DEVELOPMENT OF TRAVEL PATTERNS IN MAJOR URBAN AREAS

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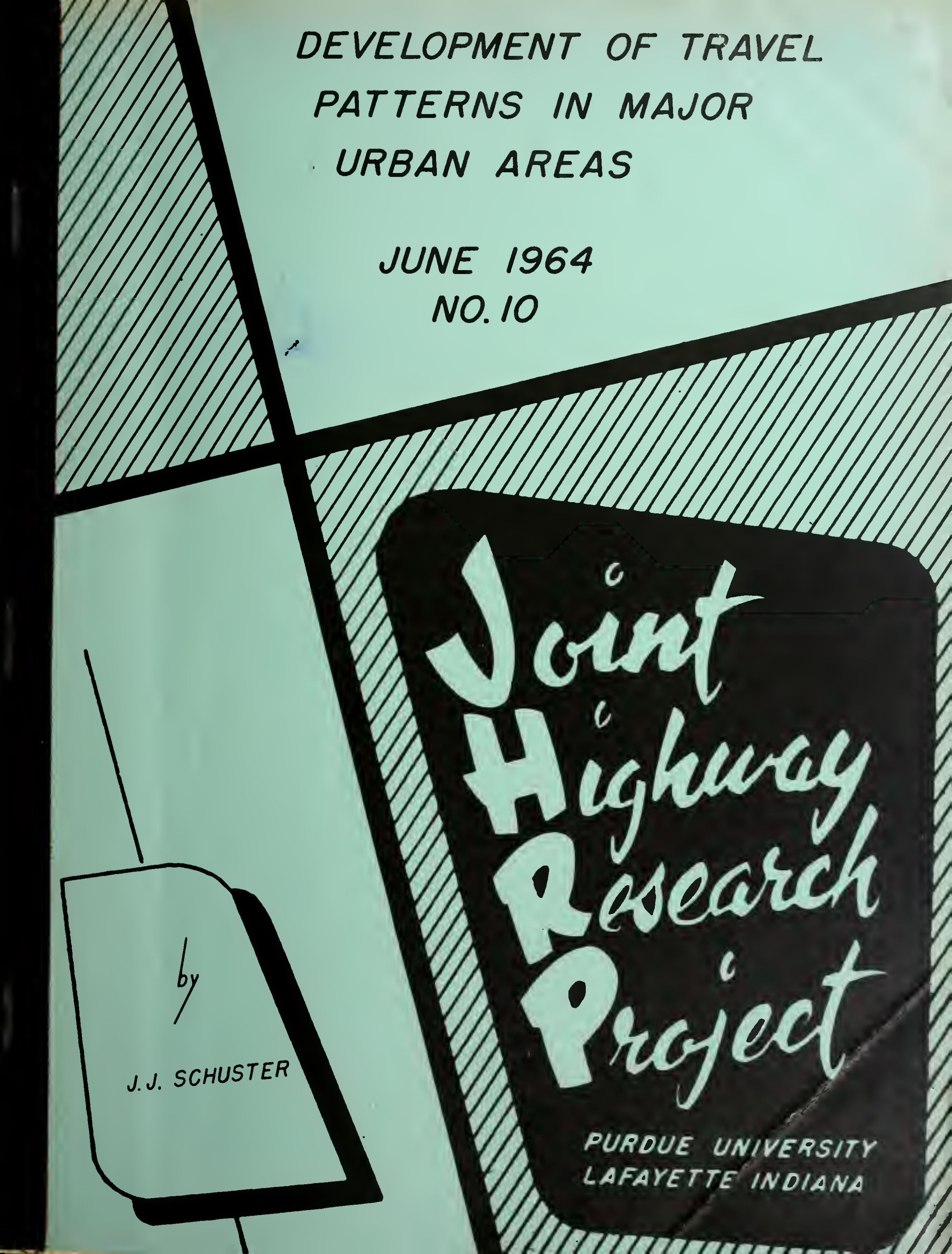

by

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DEVELOPMENT OF TRAVEL PATTERNS IN MAJOR URBAN AREAS

TO: K. B. Woods, Director
Joint Highway Research Project

June 19, 1964

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-54DD
File: 3-3-30

The Final Report on Project C-36-54DD approved by the Advisory Board on October 31, 1963 is attached. The report is titled "Development of Travel Patterns in Major Urban Areas" and it has been authored by Mr. James J. Schuster, Research Assistant on our staff, who performed the research under the direction of Professor H. L. Michael. Mr. Schuster also used this research report for his dissertation for the Ph.D. degree which he received in June 1964. He terminated his association with Purdue on May 31 and plans to return to Villanova University.

This research resulted in the development of numerous models from travel patterns found in fourteen major urban areas of the U.S. The use of these models in estimating the travel patterns in other areas of this country which have more than 100,000 and less than one million population should prove very valuable.

The research was summarized in a paper presented to the last Purdue Road School. This paper will be presented at the next meeting of the Advisory Board.

The report is presented for the record and will complete research activity on Project C-36-54DD.

Respectfully submitted,

Harold L Michael

Harold L. Michael, Secretary

HLM:bc

Attachment

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Final Report

DEVELOPMENT OF TRAVEL PATTERNS IN MAJOR URBAN AREAS

by

James J. Schuster
Research Assistant

Joint Highway Research Project

Project: C-36-54DD

File No: 3-3-30

School of Civil Engineering

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June 19, 1964

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ABSTRACT

Schuster, James John. Ph.D., Purdue University, May 1964. Development of Travel Patterns In Major Urban Areas. Major Professor: Harold L. Michael.

This research report is concerned with the development of travel patterns for urban areas by synthesis. To develop the necessary characteristics concerning vehicular trips, data were obtained for fourteen cities from the census and from recent transportation studies of these cities. Each of these cities is a part of a standard metropolitan statistical area with a population less than one million.

The study cities were: Charlotte, North Carolina; Chattanooga, Tennessee; Dayton, Ohio; Denver, Colorado; El Paso, Texas; Huntsville, Alabama; Nashville, Tennessee; New Orleans, Louisiana; Omaha, Nebraska; San Antonio, Texas; Springfield, Ohio; Toledo, Ohio; Tucson, Arizona; and Tulsa, Oklahoma. Within the study cities 75 zones were chosen in addition to the central business districts for the development of several trip prediction models. For estimating interzonal vehicle trips, 269 zonal movements in the fourteen cities were studied.

Urban vehicular trip prediction models were evolved from the data through the use of multiple regression procedures. The "tear-down" method of model evolution was utilized.

Data, which included populations, areas, population densities, automobile ownership, public transportation usage, income, occupations, distances,

school enrollment, workers, automobile usage, locations of employment, value of residences, and many interactions were used as independent variables in the development of the various models. The prediction models evolved were for total vehicle trips in a study area, ratio of external vehicle trips to total vehicle trips, ratio of local vehicle trips to internal vehicle trips, vehicle trips to and from the central business district, intrazonal central business district vehicle trips, vehicle trips generated and attracted by a zone, vehicle trips between a zone and the central business district, and interzonal vehicle trips.

Travel characteristics, including peak-hour travel, design hour volume, truck trips, and assignment of traffic to freeways, were also investigated. The latter included an analysis of freeway usage by time ratio, distance ratio, time differential, distance differential, and by a model using all four factors.

INTRODUCTION

A standard metropolitan statistical area is defined (except in New England) as a county or a group of contiguous counties which contains at least one city of 50,000 inhabitants or more or "twin cities" with a combined population of at least 50,000. In addition to the county, or counties, containing such a city or cities, contiguous counties are included in a standard metropolitan area if, according to certain criteria, they are essentially metropolitan in character and are socially and economically integrated with the central city. In New England, towns and cities rather than cities and counties are the units used in defining standard metropolitan statistical areas (SMSA) (1)*.

In 1960 there were 212 standard metropolitan areas in the United States of which 188 had a population less than one million. Table 1 shows the number of these areas in each of four ranges of population (2). Of the 180 million people in the United States in 1960, approximately 63 percent lived in these 212 metropolitan areas. The locations of the standard metropolitan statistical areas are shown in Figure 1. The projected population of the United States for 1980 is 245 million people with 75 percent of them living in urban areas (2). These urban inhabitants will perform millions of miles of daily travel within the city in which they live and a major share of it will be made by automobile. Such travel demands are

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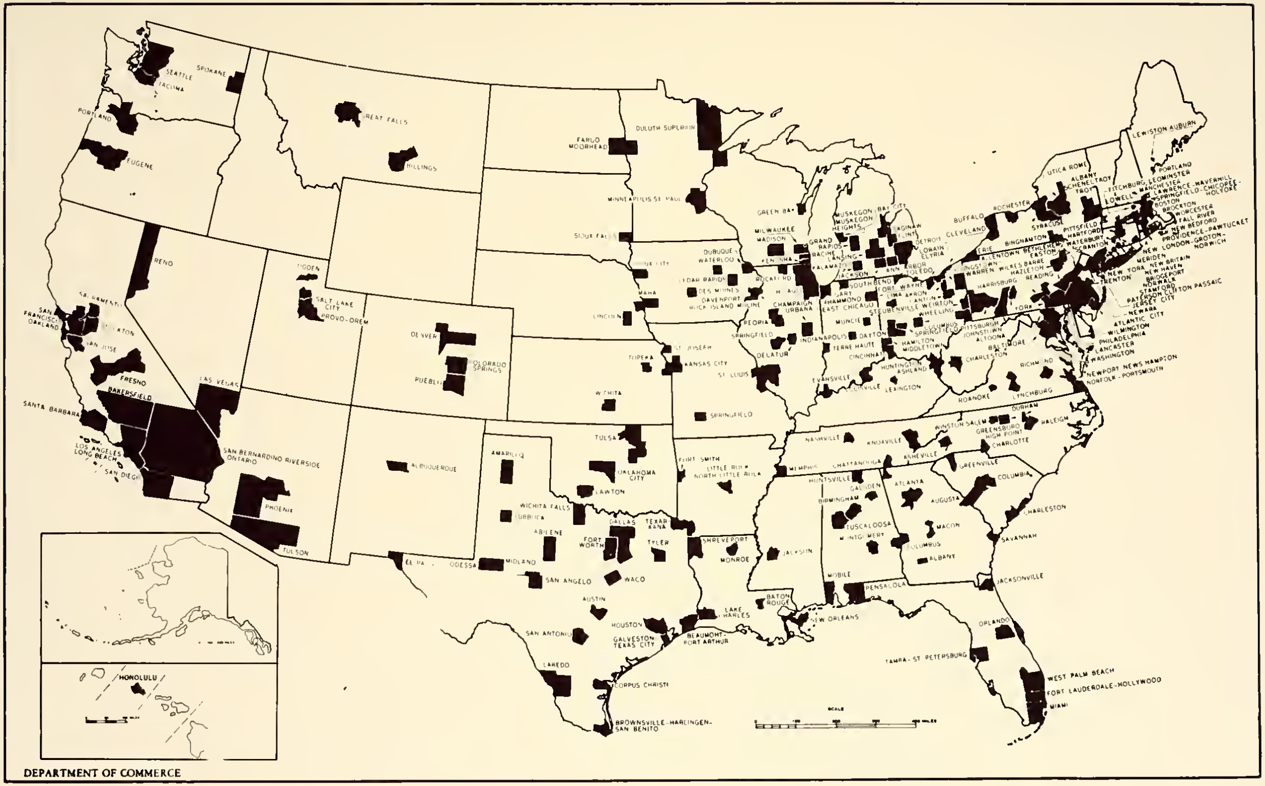
* Numbers in parentheses refer to entries in the List of References.

TABLE 1

CLASSIFICATION OF STANDARD METROPOLITAN STATISTICAL AREAS

Population Classification	No. of Areas 1960 Census	Percent of Total	Cumulative Percentage
50,000 - 100,000	22	10.38	10.38
100,000 - 500,000	137	64.62	75.00
500,000 - 1 million	39	13.68	88.68
Over 1 million	24	11.32	100.00
Total	212	100.00	



DEPARTMENT OF COMMERCE

FIG. I STANDARD METROPOLITAN STATISTICAL AREAS : 1960

requiring and will continue to demand the addition of many miles of high capacity facilities for motor vehicles.

Freeways are high-capacity highways where full control of access permits such facilities to maximize the movement function of highways. Access connections are provided with selected public streets only and crossings at grade or direct private driveway connections are prohibited.

The National System of Interstate Highways is an outstanding example of the current development of such freeways. Approximately 6700 miles of this system are planned within urbanized areas and the remaining 34,300 miles will be intercity routes. On the basis of the 1957 estimates, the completed 41,000 mile Interstate System will have some 12,000 interchanges, with an average spacing of 3.7 miles in rural areas and a spacing of less than two miles in urban areas (3). Most urban freeways that were in place in 1963 are part of the Interstate System and a high percentage of the 800 miles in 1961 that were not have similar standards (4).

The optimum location and design of a freeway and its interchanges, however, require a reasonably accurate estimate of the usage of the freeway and each interchange in the design hour of the design year. Good estimates of this usage appear to be possible from travel patterns of the city. Consequently many cities have conducted travel pattern studies, commonly known as origin-destination surveys. Such a study provides information on the current travel patterns of an individual city and techniques are available to project the patterns to a future year. These studies, however, are time-consuming and expensive. Moreover, past studies indicate a similarity of travel patterns in cities of similar size and it is generally acknowledged that travel of urban residents has many similar characteristics (5, 6).

Synthesis of these travel patterns from characteristics of the city and its inhabitants has been the subject of considerable recent study. Each of these studies, however, has generally been performed in only one city and the resulting techniques have not been entirely satisfactory when applied to another city.

Several of the cities in the standard metropolitan statistical areas have had recent transportation studies, including origin-destination. The possibility existed, therefore, of analyzing the results of several of these studies in the hope that techniques and models for synthesizing the travel patterns of cities of similar size in these areas could be developed.

Purpose and Scope

The purpose of this research was to develop a method for synthesizing urban travel patterns through an evaluation of various factors which affected travel patterns in fourteen urban areas.

The study included an investigation of travel pattern characteristics in standard metropolitan statistical areas less than one million population. This population classification was chosen because of the possible homogeneity in the factors affecting transportation facilities. Statistical analyses of data from the fourteen cities were made to evaluate correlations in urban travel pattern characteristics. Urban vehicular trip patterns and characteristics of peak-hour travel, design hour volume, truck trips, traffic generation of the central business district, and freeway usage were among those investigated.

PREVIOUS INVESTIGATIONS

It is extremely helpful in the planning of transportation facilities to know where similarity exists with respect to travel characteristics in urban areas. Many metropolitan area studies have been completed under the co-sponsorship of the United States Department of Commerce, Bureau of Public Roads, the respective state highway departments, and local governments and in all such studies certain characteristics of the travel patterns for the study city were evaluated. Considerable similarity in some of these characteristics was noted early and several summaries have been published.

In the report, Future Highways and Urban Growth, twelve cities were chosen and many travel characteristics tabulated (4). In reference to urban travel pattern characteristics, the following conclusions were drawn: (a) the urban resident makes about two trips per day in a car or transit vehicle in large cities and two and one half or more trips in small cities; (b) in all cities, the resident travels about ten miles each day in all pursuits; (c) approximately 20 percent of all daily urban trips are to work, 18 percent for business and shopping, 12 percent for social and recreational purposes, 40 percent to home, 3 percent to school, and 7 percent for miscellaneous reasons; (d) in all but a handful of large cities, the automobile now accounts for more than 85 percent of all urban travel and is usually the dominant form of transportation for persons entering the downtown area; (e) the transit pattern is predominantly focused on the central business

district whereas automobile travel is diffused throughout the urban area; (f) travel mode is related to car ownership, population density, and family income.

Another report on travel characteristics in urban areas tabulated information that was obtained from origin-destination traffic surveys of the home interview type in 50 cities between 1945 and 1954 (7). About 30 percent of these cities had been surveyed during World War II and the travel patterns could be biased because of fuel rationing, shortage of new automobiles, and other factors. It can be concluded from the data, however, that factors such as population and population density might be used as good predictors in the determination of urban trips.

An excellent report on the current principles and techniques of traffic estimation and assignment is, Principles and Techniques of Predicting Future Demand for Urban Area Transportation. It is a compendium of the presently available and utilized methods for predicting urban transportation demand (8). The conclusion is drawn that inventories of existing conditions and the estimates of future urban area growth can be utilized in the determination of future urban travel demand. Some of the factors which must be considered in the inventories and future estimates are land use, population, vehicle ownership, monetary resources, and economic activity.

Multiple regression techniques have been used for estimating trip generation, but its use has been restricted to individual urban areas (9). The validity of using inferences drawn from one city in other cities is questionable. California has used the same general form of multiple regression equation for each of the cities of Modesto, San Diego, and Vallejo (10). The steps involved in the California multiple regression method are:

(a) Select an equation form determined from experience and theory. Using trip interchange and independent variable values from a sample origin-destination survey, obtain a set of coefficients for the study city.

(b) Estimate the theoretical trips in the survey period by using the coefficients and the independent variable values of step (a). Analyze the difference between theoretical and survey trips. Repeat step (a) if the analysis warrants modification of the equation form.

(c) Estimate the independent variables of the design year.

(d) Use the estimated independent variables of the design year with the determined coefficients to calculate the theoretical trips of the design year.

The model used in the three California cities were:

Modesto - $Y = B_0 + B_1 \frac{P}{(1+D)^2} + B_2 \frac{E^2}{(1+D)^2} + B_3 \frac{V}{(1+D)^2} + B_4 \frac{L}{(1+D)^2}$

San Diego - $Y = B_0 + B_1 \frac{P^2}{D^{1.5}} + B_2 \frac{E^2}{D^{1.5}} + B_3 \frac{V}{D^{1.5}} + B_4 \frac{L}{D^{1.5}}$

Vallejo - $Y = B_0 + B_1 \frac{(PV)^{1/2}}{(1+D)^2} + B_2 \frac{E^2}{(1+D)^2} + B_3 \frac{V^2}{(1+D)^2} + B_4 \frac{I}{(1+D)^2}$

where: B_i = constant. $i = 0, 1, 2, 3, 4$.

Y = trips between zones.

D = straight line distance between zones.

P = population in each zone.

E = employed persons in each zone.

V = vehicles owned in each zone.

I = industrial acreage in each zone.

L = land use index of each zone.

The amount of variation (R^2) in trips between zones explained by these variables in these cities was not available.

Many other similar studies of travel pattern have been conducted throughout the United States but no research was found where the travel patterns of several cities were analyzed to develop trip pattern prediction models.

STATISTICAL ANALYSIS PROCEDURES

One of the most important tools available to the planner is statistics. Particularly in the field of trip prediction, the techniques of simple regression, multiple regression, and model evolution are extremely useful. One important statistical measure is the square of the correlation coefficient with a given sample size. This provides a measure of the amount of variability of a dependent variable that is explained by the independent variable or variables. This explained variation is referred to as the coefficient of determination in regression analysis, which assumes that the independent variable or variables are fixed and measured without error while the dependent variable is normally and independently distributed. This important asset is illustrated in Figure 2 for the case of simple regression where the sample size is equal to nine for all cases. The negative value for a simple correlation coefficient means that the slope of the line, that is the regression coefficient, is negative. It is impossible to illustrate the multiple regression case for more than two independent variables for it is in the realm of dimensional space theory. The y intercept, that is, where x is equal to zero, is represented by B_o in the general model evolved through multiple regression.

The evolution of models from data using multiple regression procedures allows the acquisition of maximum information from collected data. Without the use of a computer, model evolution would be impossible due to the enormous amount of calculations. Two procedures available for evolving a model are the "build-up" and the "tear-down". The former method involves

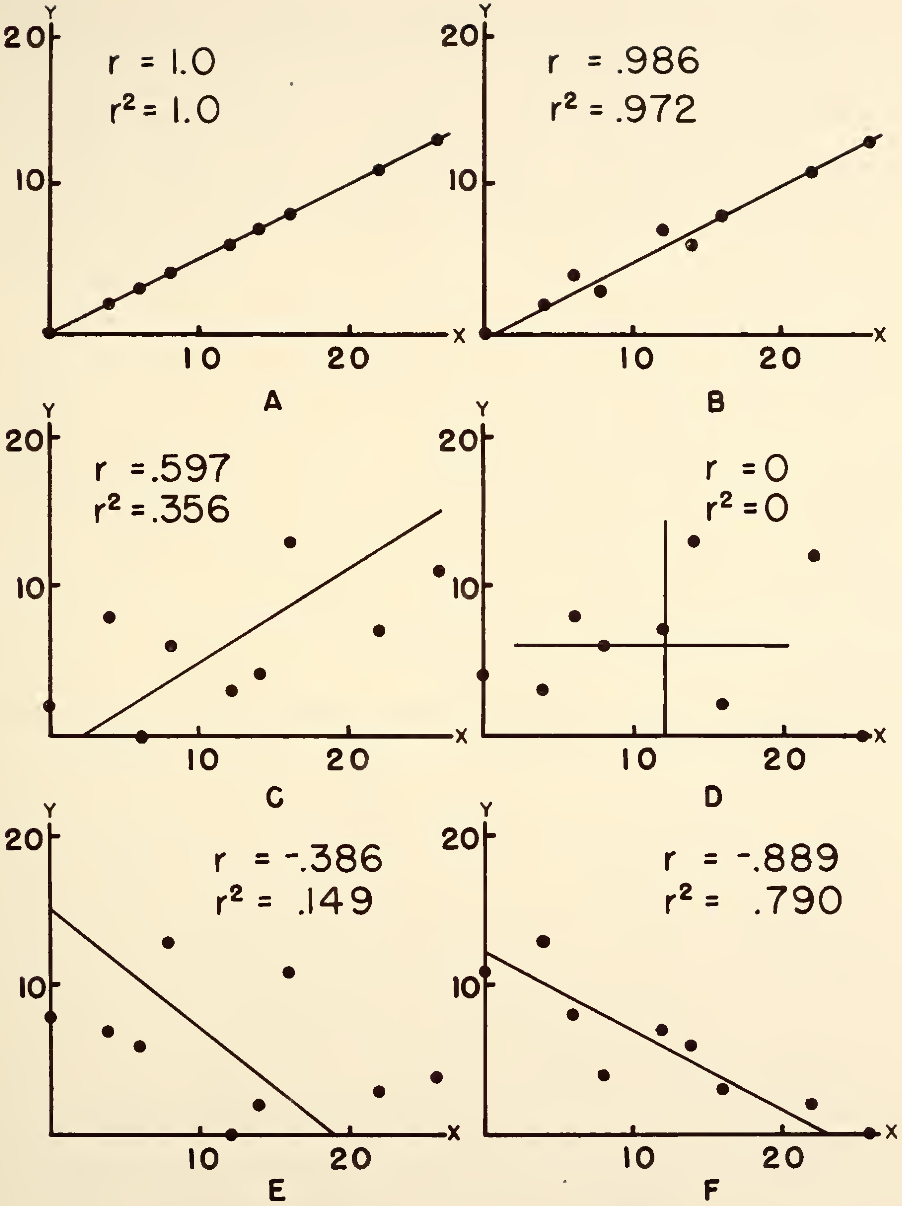


FIG. 2 SCATTER DIAGRAMS WITH CORRELATION COEFFICIENTS

finding the simple correlation coefficients among all independent and dependent variables and then selecting the variables to go into the model. Independent variables which do not add enough explained variation of the dependent variable to warrant their inclusion in the model are not included. To examine the amount of additional explained variation, the F-test is generally utilized.

There is more flexibility in the choice of variables to be included in the final model in the "tear-down" method. At first, all independent variables are in the model. Then subsets usually consisting of those independent variables which have the largest simple correlations with the dependent variable and the smallest simple correlations with the independent variable are tested. There may be reason to retain certain variables in the model and this may be accomplished by including them in the subsets. Many subsets are tried and a comparison is made on the fractional amounts of variation in the dependent variable explained by the independent variables before a model is finally decided (11).

It is important to realize in model evolution that it is up to the experimenter to set the level of significance for testing of hypotheses, and this need not always be at the .05 level. The level of significance selected should depend on the consequences of rejecting a true hypothesis. The chosen level of significance, in fact, may change as one proceeds with repeated statistical tests. An example of this occurs in the repeated F-tests in model evolution where the true level of significance increases as the number of tests increase. The experimenter might therefore have some variables in the model when they are not very important, but the model will include most variables that importantly influence the dependent variable.

If an increase of the true level of significance is undesirable, one may decrease the tabulated level of significance with successive testing. On the other hand, in certain tests the experimenter may want to increase the level of significance so that he will be sure of the hypothesis he accepts; that is, an increase in power is desired. Therefore, it is evident that one should set the level of significance to fit his needs, which may be influenced by cost of data, difficulty in the collection of data, or other factors. The definitions of these various statistical terms are given in Appendix B.

Another element that must be considered in model evolution is the use of the final model. In planning studies it is often necessary to predict future trips from future land use areas. It is necessary to assume that the factors that affect present day trips will also affect future trips if a model evolved from present day trip data is used for trip prediction. Preference may therefore be given to certain variables which are expected to have similar influences today and in the future even though the highest correlation coefficient may not be attained.

The general model evolved through multiple regression is of the following form (11):

$$Y_i = B_o + B_1 X_{1i} + B_2 X_{2i} + \cdots B_k X_{ki} + e_i$$

where:

Y_i = ith observed value of the dependent variable

B_o = parameter

B_i = parameter. $i = 1, 2, \cdots k$

X_{ji} = the ith observation of the jth independent, fixed variable, which could be an interaction such as X_1X_2, X_1^2, X_2^2, etc. $j = 1, 2, \cdots j \cdots k$ and $i = 1, 2, \cdots n$.

The estimating model is of the following form:

$$y_i = b_o + b_1 x_{1i} + b_2 x_{2i} + \cdots b_k x_{ki} + e_i.$$

Where:

b_o = least square estimate of B_o

b_i = least square estimate of B_i

e_i = the ith residual.

To use the above models the three basic assumptions outlined below must be made for tests of significance and confidence intervals.

a. The independent variables are fixed and measured without error.

b. For a set of independent variables, the dependent variable is normally and independently distributed.

c. For any set of independent variables the variances of the dependent variables are homogeneous.

To test a multiple R^2 for significance of difference from zero in multiple regression, the null hypothesis may be stated as:

$$H:\ R^2 y \cdot x_1, x_2, \cdots x_k = 0$$

or,

$$H:\ B_1 = B_2 = \cdots = B_k = 0$$

To test the null hypothesis, the F distribution is used.

$$F_{k,\ n-k-1} = \frac{\text{mean square due to regression}}{\text{mean square deviation from regression}}$$

$$= \frac{(SS_y)\ R^2/k}{(SS_y)\ (1-R^2)/n-k-1}$$

$$= \frac{R^2/k}{(1-R^2)/n-k-1}$$

where:

SS_y = sum of squares of y

k = number of independent variables

n = sample size

In model evolution the magnitude of R^2 is non-decreasing as the number of independent variables increase. It is sometimes necessary to test whether the multiple R_k^2 for all k independent variables is significantly greater than the R_r^2 for a subset of r independent variables. The null hypothesis then is:

$$H: R_y^2 \cdot X_1, X_2, \cdots X_k = R_y^2 \cdot X_1, X_2, \cdots x_r$$

To test the null hypothesis, the F distribution is used.

$$F_{k-r, n-k-1} = \frac{\dfrac{R_k^2 - R_r^2}{k-r}}{\dfrac{1 - R_k^2}{n-k-1}}$$

URBAN TRAVEL PATTERN DEVELOPMENT

General

For the location and design of a transportation facility a knowledge of the volume of vehicles using the facility at the design hour is imperative. The usual procedure for securing an estimate of such volumes is through an analysis of the travel patterns of the city as determined by an origin-destination survey. Such a survey, however, may not be available or possible of completion before the location of a freeway and its interchanges are necessary. It may be possible, furthermore, to develop methods for estimating the travel patterns of a city from travel pattern characteristics in cities of similar size.

To evaluate the possibility of estimating trip patterns of a city in a standard metropolitan statistical area, data were obtained and analyzed from fourteen such cities that had completed a transportation study. This study was restricted to cities with a statistical area population of less than one million. The study locations and dates of the transportation studies, are listed in Table 2. The studies were relatively recent with the average date being 1958.

For each of the fourteen study cities there were five basic areas, the central business district, the 1960 city area, the 1960 urbanized area, the 1960 standard metropolitan statistical area, and the transportation study area. The organization that performed each transportation study

TABLE 2

STUDY CITIES AND DATES OF TRANSPORTATION STUDY

City	Date of Transportation Study
Charlotte, North Carolina	1958-60
Chattanooga, Tennessee	1960-62
Dayton, Ohio	1957
Denver, Colorado	1961-62
El Paso, Texas	1958
Huntsville, Alabama	1959-60
Nashville, Tennessee	1959-61
New Orleans, Louisiana	1959-60
Omaha, Nebraska	1955-56
San Antonio, Texas	1956
Springfield, Ohio	1956
Toledo, Ohio	1957
Tucson, Arizona	1960
Tulsa, Oklahoma	1954-55

delimited the central business district and the entire transportation study area. In all cases the latter area was larger than the city area and smaller than the standard metroppolitan statistical area. The area classified as central business district varied considerably in size between cities, a result of differences in definition of the composition of the CBD. The values and the ranges for the five basic areas are shown in Table 3.

In all cases the 1960 standard metropolitan statistical area contained the largest population. The population of the 1960 urbanized area was closer in magnitude to the transportation study population but the difference in dates should be noted for an accurate comparison. The populations for four of the basic areas are listed in Table 4, the average areas and populations of the study cities are graphically portrayed in Figure 3 and the locations are shown in Figure 4.

In the conduct of this research, data used were obtained from the 1960 Census and from the fourteen transportation studies. Much of the data from the transportation studies used "dwelling unit" as defined by the 1950 Census as a basic unit. The data from the 1960 Census used "housing unit" as the basic unit. Although the definitions of "housing unit" and "dwelling unit" were essentially similar, the "housing unit" definition encompassed all private living quarters while the "dwelling unit" definition did not cover all private living accommodations.

The main difference between "housing units" and "dwelling units" was in the treatment of one-room quarters. In 1960, separate living quarters consisting of one room with direct access but without separate cooking equipment qualified as a housing unit whether in an apartment house,

TABLE 3

AREAS OF FOURTEEN STUDY CITIES - mi^2

City	Transportation Study	1960 SMSA	1960 Urbanized Area	City Area	CBD
Charlotte	120	542	73.9	64.8	0.725
Chattanooga	205	1021	89.1	36.7	0.384
Dayton	129	1288	124.5	33.6	0.593
Denver	420	3665	166.6	71.0	0.558
El Paso	162	1054	115.0	114.6	0.152
Huntsville	65	803	53.2	50.7	0.120
Nashville	235	532	129.3	29.0	0.579
New Orleans	250	1118	266.5	198.8	0.690
Omaha	116	1533	89.0	51.2	0.348
San Antonio	192	1247	192.4	160.5	0.456
Springfield	58	402	20.6	15.7	0.135
Toledo	120	343	134.9	48.2	0.256
Tucson	610	9241	86.4	70.9	0.202
Tulsa	92	3824	70.2	47.8	0.424
Range	58-610	343-9241	20.6-266.5	15.7-198.8	0.120-0.725

TABLE 4

POPULATIONS OF FOURTEEN STUDY CITIES

City	Transportation Study	1960 SMSA	1960 Urbanized Area	1960 City
Charlotte	202262	272111	209551	201564
Chattanooga	241709	283169	205143	130009
Dayton	425000	694623	501664	262332
Denver	816700	929383	803624	493887
El Paso	268968	314070	277128	276687
Huntsville	73260	117348	74970	72365
Nashville	357585	399743	346729	170874
New Orleans	855551	868480	845237	627525
Omaha	296449	457873	389881	301598
San Antonio	586586	687151	641965	587718
Springfield	99020	131440	90157	82723
Toledo	405000	456931	438283	318003
Tucson	242550	265660	227433	212892
Tulsa	240419	418974	298922	261685
Range	73260-855551	117348-929383	74970-845237	72365-627525

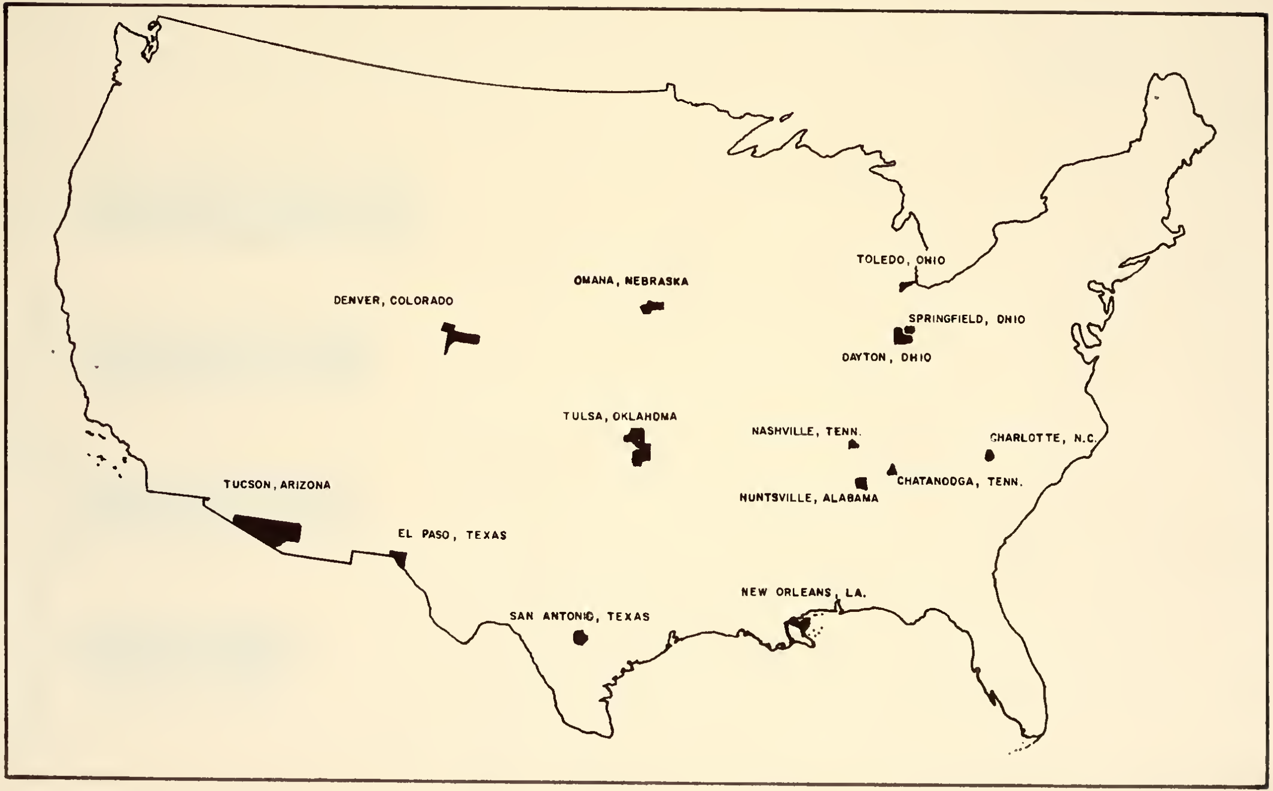


FIG. 4 LOCATION OF FOURTEEN STUDY AREAS

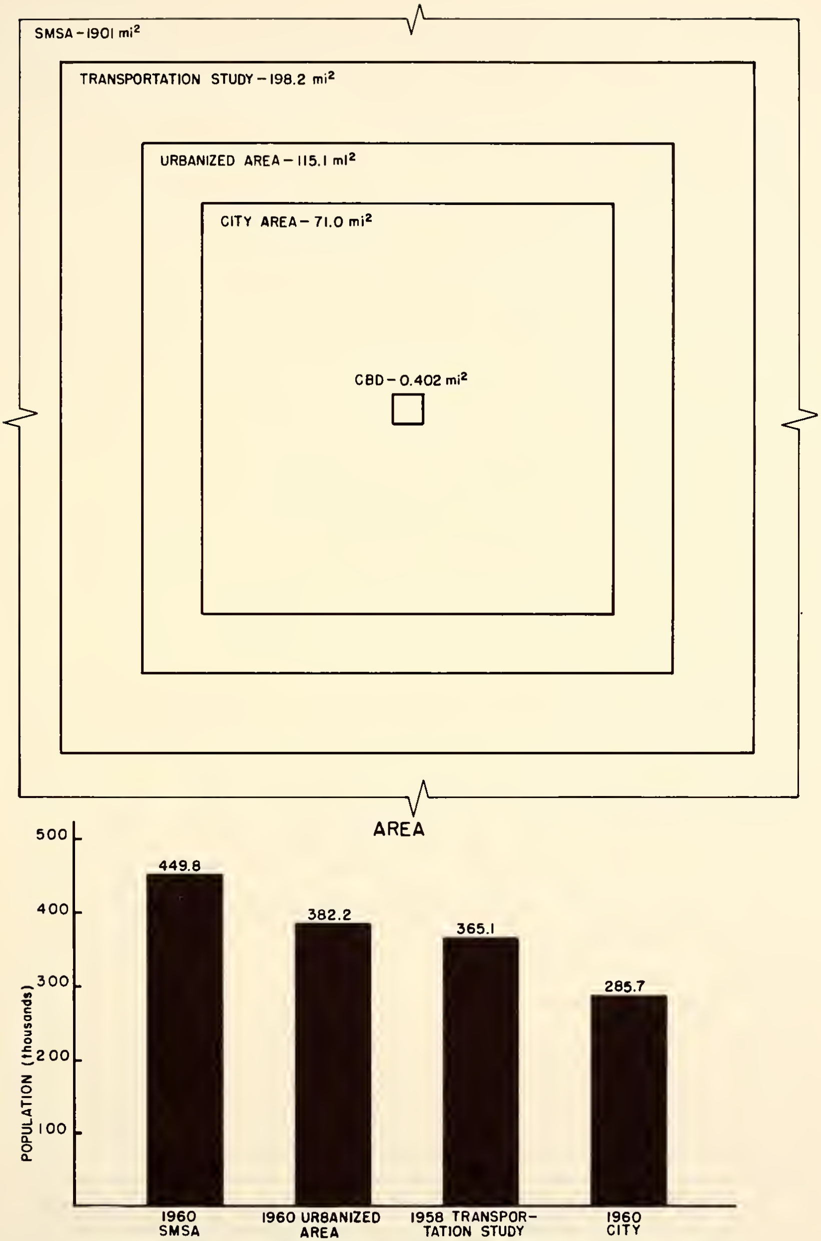


FIG. 3 AVERAGE AREAS AND POPULATIONS OF STUDY LOCATIONS

rooming house, or house converted to apartment use; in hotels, a single room qualified as a housing unit if occupied by a person whose usual residence was the hotel or by a person who had no usual residence elsewhere. In 1950, a one-room unit without cooking equipment qualified as a dwelling unit only if it was located in a regular apartment house or if it constituted the only living quarters in the structure. In hotels, in 1950, occupied and vacant quarters were counted as dwelling units only if more than half the accommodations in the hotel were for permanent quests; if less than half, all quarters were excluded. The difference in definition, however, had relatively little effect on comparability of the data for large areas.

Further data that were used to develop the models for the study cities are shown in Table 5 and a more detailed description of these variables follows.

a. Population density for the transportation study area. This was determined by dividing the transportation study population by the study area.

b. Percent of occupied housing units in the standard metropolitan statistical area with one or more available automobiles. Available to a housing unit represent passenger automobiles, including station wagons, owned or regularly used or ordinarily kept at home, such as some company cars, by any of the occupants of the unit. Taxicabs, pickups or larger trucks, and dismantled or dilapidated cars in an early stage of being junked were not included.

c. Percent of employed persons in the standard metropolitan statistical area using public transportation to work. These data refer to transportation used during the week prior to census enumeration by the civilian population for work trips and by Armed Forces personnel not on leave. Public transportation included railroads, subways, elevated railways, buses, and streetcars. Persons using more than one means of transportation in daily travel were classified according to the "principal means" used, that is, the means covering the greatest distance, or the means most frequently used if different means were used on different days.

d. Median income in 1959 of families in the standard metropolitan statistical area. Family income represent, as a single amount,

TABLE 5

POPULATION DENSITY AND CENSUS DATA FOR STUDY CITIES

City	Population Density pers/mi^2	Percent of Units with 1 Automobile*	Percent of Employed Using Public Transportation to Work	Median Income of Families	Percent of White-Collar Workers
Charlotte	1686	49.5	13.1	$5632	45.7
Chattanooga	1179	54.7	10.5	4958	38.3
Dayton	3295	61.0	9.8	6687	42.6
Denver	1945	50.7	9.2	6551	52.5
El Paso	1660	57.3	12.2	5157	48.1
Huntsville	1132	60.0	2.6	5426	45.8
Nashville	1524	53.5	15.0	5332	45.9
New Orleans	3422	49.9	30.1	5195	45.2
Omaha	2545	60.3	13.6	6221	47.2
San Antonio	3054	56.1	9.9	4766	46.0
Springfield	1693	62.2	6.5	5825	40.9
Toledo	3375	59.1	10.6	6533	43.2
Tucson	397	57.0	3.3	5690	46.5
Tulsa	2602	56.7	7.1	5729	48.3
Range	397-3422	49.5-62.2	2.6-30.1	$4766-6687	38.3-52.5

* 1 or more

the combined income of the head of the family and all other members of the family fourteen years old and over. Income was the sum of money received in 1959 from sources which included wages, salary, income from self-employment, rents, royalties, interest, pensions, public assistance and alimony. The figures represent the amount of income received before deductions for personal income taxes, social security, etc.

e. Percent of employed persons in the standard metropolitan statistical area in white-collar occupations. Employed persons comprise all civilians fourteen years old and over who did any work for pay or profit and who were either "at work" or "with a job but not at work at the time of the enumeration." White-collar occupations refer to the following groups: "professional, technical, and kindred workers; managers, officials, and proprietors, except farm; clerical and kindred workers; sales workers."

In addition to the above variables, many interactions were used in evolving the various models. Interaction is the differential response to one factor in combination with varying levels of a second factor applied simultaneously. That is, interaction is an additional effect due to the combined influence of two or more factors (12).

Total Vehicle Trips in a Study Area

Total vehicle trips in a study area are comprised of both the internal and external one-way movements. An internal trip has both the origin and the destination within the confines of the delimited study area and includes interzonal trips and intrazonal trips. An external trip may have one or both ends of the trip outside the study area and includes external-internal trips (called local trips in this study) and through trips.

It would be erroneous to compare only the internal trips among the fourteen locations because of the variability that exists in the delimiting of the study area. It is obvious that the number of internal trips will increase as the transportation area increases. The percent of total vehicle

trips that were internal trips ranged from 75.2 to 96.3 as shown in Table 6. This table also lists the total number of vehicle trips and the estimated number of vehicle trips as determined from the model described in the following paragraphs.

In addition to the data previously described, two interactions were investigated to evolve a model for the total vehicle trips per day in a study area. These terms were the transportation study area by the transportation study population and the transportation study population by the transportation study population density. Nine subsets containing various combinations of the independent variables were tried and tested and the model evolved follows:

$$Y = + 142010 + 1.53441\ X_1 - 8731.8\ X_5 \qquad \text{(I)}$$

where:

Y = total number of vehicle trips per day in a study area

X_1 = transportation study population

X_5 = percent of employed persons using public transportation to work

The amount of variability (R^2) explained by this model is 96.9 percent. The analysis of variance for this model is shown in Table 7. A measure of the variability in total vehicle trips that is explained by various independent variables alone may be obtained by squaring the simple correlation coefficients for the dependent variable, $Y = X_6$, and each of the independent variables as shown in Table 8. Shown in the same table are the simple correlation coefficients between each of the independent variables.

TABLE 6

TOTAL VEHICLE TRIP DATA

City	Percent Internal Trips	Total Vehicle Trips	Estimated Total Vehicle Trips	Residual
Charlotte	78.6	433686	337976	95710
Chattanooga	84.6	419765	421206	- 1441
Dayton	77.4	743939	708562	35377
Denver	95.9	1365766	1314829	50937
El Paso	88.5	437166	448189	-11023
Huntsville	77.6	134454	231718	-97264
Nashville	87.5	600154	559715	40439
New Orleans	95.1	1122208	1191948	-69740
Omaha	86.9	463731	478132	-14401
San Antonio	92.0	873756	955628	-81872
Springfield	75.2	212255	237190	-24935
Toledo	78.8	766097	670888	95209
Tucson	96.3	457499	485366	-27867
Tulsa	84.2	459787	448915	10872
Range	75.2-96.3	134454-1365766		

TABLE 7

ANALYSIS OF VARIANCE FOR TOTAL VEHICLE TRIPS

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	2	14474.60×10^8	7237.30×10^8	170.91
Deviations About Regression	11	465.81×10^8	42.35×10^8	
Total	13	14940.41×10^8		

TABLE 8

SIMPLE CORRELATION COEFFICIENTS FOR TOTAL VEHICLE TRIPS

X_1 = TRANSPORTATION STUDY POPULATION

X_2 = TRANSPORTATION STUDY AREA

X_3 = TRANSPORTATION STUDY POPULATION DENSITY

X_4 = PERCENT UNITS WITH ONE AUTOMOBILE

X_5 = PERCENT USING PUBLIC TRANSPORTATION TO WORK

$Y = X_6$ = TOTAL VEHICLE TRIPS IN STUDY AREA

$X_7 = X_1 X_2$

$X_8 = X_1 X_3$

	X_1	X_2	X_3	X_4	X_5	$Y=X_6$	X_7	X_8
X_1	1.000							
X_2	.376	1.000						
X_3	.558	-.396	1.000					
X_4	-.554	-.383	.033	1.000				
X_5	.621	-.045	.511	-.551	1.000			
$Y=X_6$	.975	.411	.536	-.545	.501	1.000		
X_7	.849	.718	.085	-.594	.310	.865	1.000	
X_8	.916	.090	.794	-.373	.707	.853	.597	1.000

Effect of Study Population and Area

The ratios of external vehicle trips to total vehicle trips and local vehicle trips to internal vehicle trips vary with the size of the transportation study population and area, as shown in Figures 5 and 6. The lines shown are least squares fits of data obtained from the fourteen study areas. It is easily seen that as the area increases, population increases with the effect that less trips are included in the external portion of the survey. The daily vehicle trip data for the study cities, including internal trips, local trips, through trips, external trips and total trips are shown in Table 9.

It was desired to know if the ratio of external trips and local trips to total trips could be estimated from the factors of population and area. The following models were evolved for this purpose.

$$Y = 0.4126 + 10^{-10} \left[0.0242\ X_1 X_2^2 - 4644.2\ X_1 - 11351\ X_2^2 + 452.1\ (X_1/X_2)^2 - 1576380\ (X_1/X_2) \right] \qquad \text{(II)}$$

where:

Y = ratio of external vehicle trips per day to total vehicle trips per day

X_1 = transportation study population

X_2 = transportation study area in square miles

and:

$$Y = +\ 0.545 + 10^{-7} \left[-\ 0.0267\ X_1 X_2 - 17.4\ X_2^2 + 7.00\ (10^{-5})\ X_1 X_2^2 + 0.656\ (X_1/X_2)^2 - 2774\ (X_1/X_2) \right] \qquad \text{(III)}$$

where:

Y = ratio of local vehicle trips per day to internal vehicle trips per day

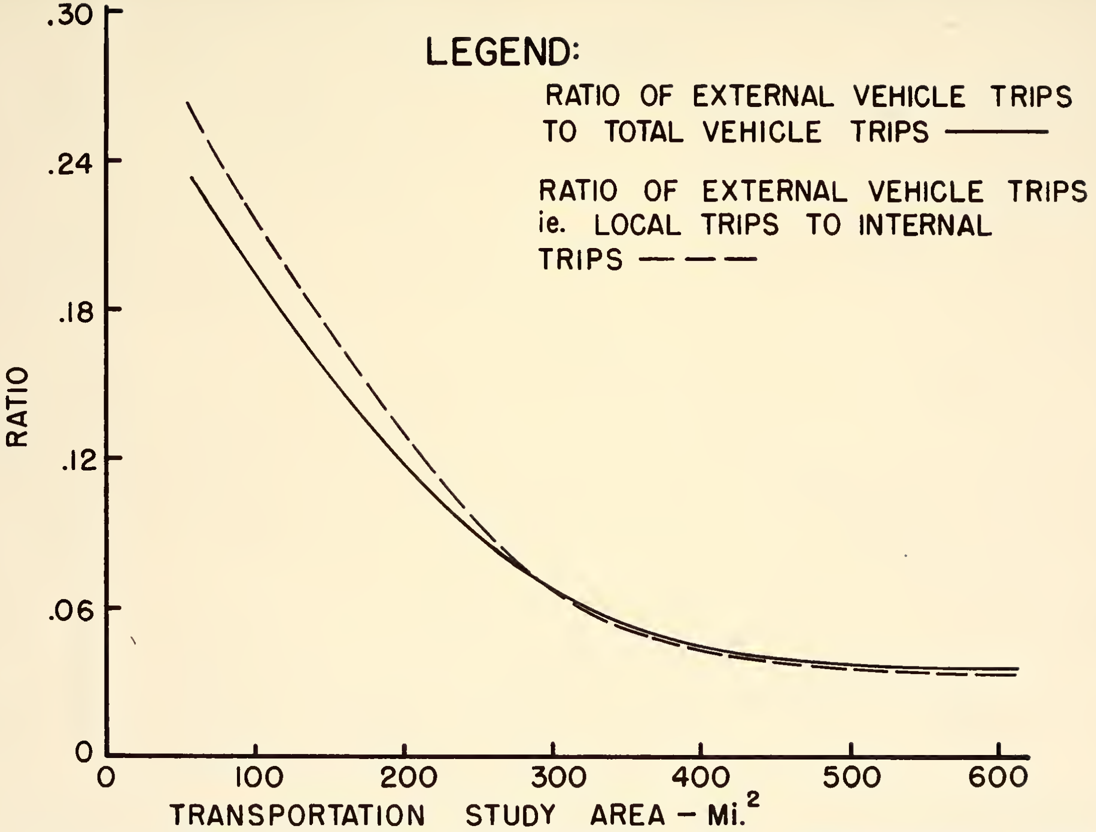


FIG. 5 RELATION OF EXTERNAL TRIPS AND TRANSPORTATION STUDY AREA

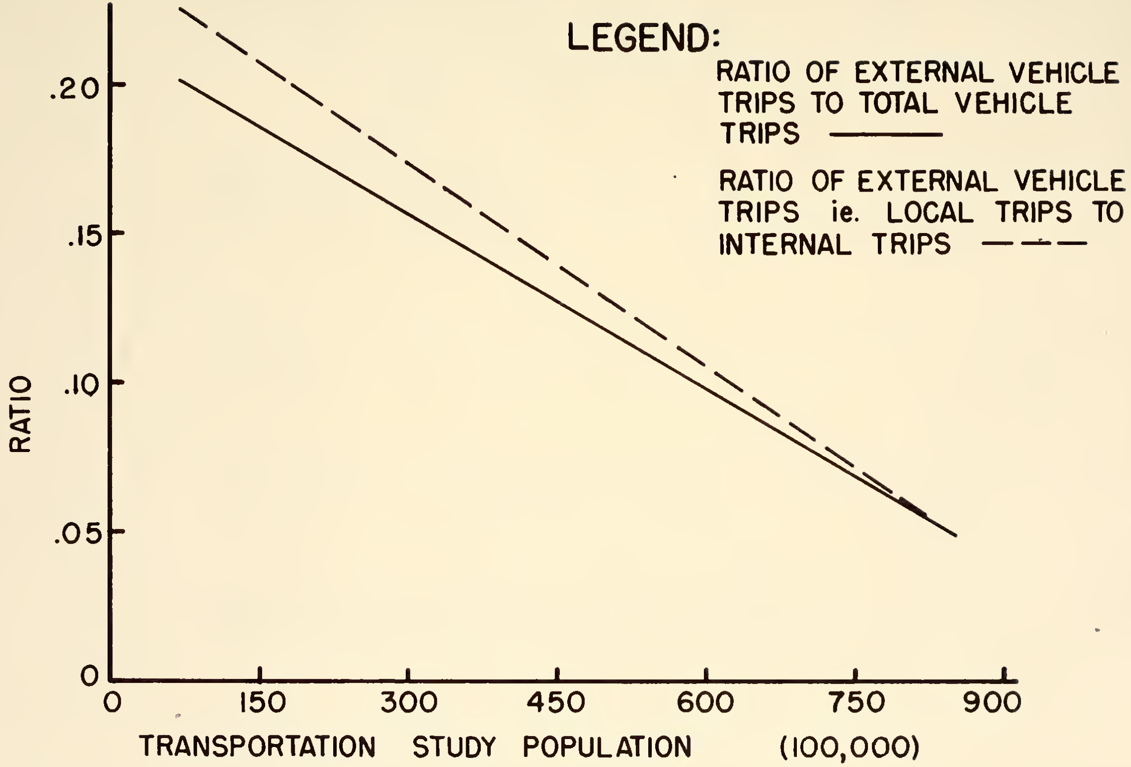


FIG. 6 RELATION OF EXTERNAL TRIPS AND TRANSPORTATION STUDY POPULATION

TABLE 9

VEHICLE TRIP DATA

City	Internal Trips	External Trips			Total Trips
		Local Trips	Through	Sub-Total	
Charlotte	340915	85553	7218	92771	433686
Chattanooga	355257	59903	4605	64508	419765
Dayton	575563	160219	8157	168376	743939
Denver	1297673	64079	4014	68093	1365766
El Paso	386830	47532	2804	50336	437166
Huntsville	104337	27500	2617	30117	134454
Nashville	525078	69199	5877	75076	600154
New Orleans	1067534	52373	2301	54674	1122208
Omaha	402868	54987	5876	60863	463731
San Antonio	803396	64074	6286	70360	873756
Springfield	159725	42880	9650	52530	212255
Toledo	603687	143580	18835	162415	766097
Tucson	440465	15963	1071	17034	457499
Tulsa	386900	67062	5825	72887	459787

X_1 = transportation study population

X_2 = transportation study area in square miles

The amounts of variability (R^2) explained by these models are 87.5 percent and 85.8 percent respectively. The analysis of variance for the models are shown in Tables 10 and 11. The simple correlation coefficients for both ratios are shown in Table 12.

Central Business District

The central business district is the largest traffic generator when considering vehicle trip ends per square mile as a measure of generation. For the central business districts and the next largest generators the number of vehicle trip ends per square mile and the ratio of the two are shown in Table 13 for the fourteen cities.

Vehicle Trips to and from the Central Business District

The internal and external vehicle trips per day to and from the central business district consist of those trips that had either their origin or destination in that particular zone. These trips had an average of 73556 and ranged from 22855 in Huntsville to 119640 in New Orleans.

To evolve a univariate model for this dependent variable seventeen subsets containing various combinations of eleven independent variables were tried and tested. The following model was evolved:

$$\begin{aligned} Y &= -39570 + 0.04948\, X_1 + 41335\, X_2 \\ &\quad -1443.9\, X_5 + 1492.0\, X_7 + 28.755\, X_{11} \end{aligned} \qquad \text{(IV)}$$

where:

Y = vehicle trips to and from the central business district per day

X_1 = transportation study population

TABLE 10

ANALYSIS OF VARIANCE FOR RATIO OF EXTERNAL TRIPS TO TOTAL TRIPS

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	5	598.52	119.70	11.18
Deviations About Regression	8	85.69	10.71	
Total	13	684.21		

TABLE 11

ANALYSIS OF VARIANCE FOR RATIO OF LOCAL TRIPS TO INTERNAL TRIPS

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	5	85.850×10^{-3}	17.170×10^{-3}	9.63
Deviations About Regression	8	14.259×10^{-3}	1.782×10^{-3}	
Total	13	100.109×10^{-3}		

TABLE 12

SIMPLE CORRELATION COEFFICIENTS FOR AREA AND POPULATION

	X_1	X_2
X_1	1.000	
X_2	0.376	1.000
Y_1	-0.640	-0.780
Y_2	-0.617	-0.756

X_1 = transportation study population

X_2 = transportation study area

Y_1 = ratio of external trips to total trips

Y_2 = ratio of local trips to internal trips

TABLE 13

TRAFFIC GENERATING CHARACTERISTICS OF THE CENTRAL BUSINESS DISTRICT

City	Trips Ends per mi^2	Largest Generator Outside CBD Trip Ends per mi^2	Ratio of CBD to Next Largest Generator
Charlotte	142055	18866	7.53
Dayton	207344	101539	2.04
Denver	250269	39196	6.39
El Paso	355974	30349	11.73
Huntsville	201058	14990	13.41
New Orleans	213901	44730	4.78
Omaha	203101	48438	4.19
San Antonio	298055	34471	8.65
Springfield	312319	43222	7.23
Toledo	261387	17498	14.94
Tucson	229446	53747	4.27
Tulsa	241870	86236	2.80
Range	142055-355974	14990-101539	2.04-14.94

X_2 = area of the central business district in square miles

X_5 = percent of employed persons using public transportation to work

X_7 = percent of employed persons who had white collar occupations

X_{11}= the interaction of the area of the central business district by the transportation study population density.

The amount of variability (R^2) explained by this model is 94.4 percent. Table 14 shows the analysis of variance, and the true, estimated, and residual of vehicle trips to and from the central business district are shown in Table 15. The simple correlation coefficients between the various variables used in the model are shown in Table 16.

For the fourteen locations there was an average of 13.36 percent of the total vehicle trips that had an origin or destination in the central business district and the range was from 7.80 percent in Toledo to 20.27 percent in Tulsa. The relationship between the daily vehicle trips to and from the central business district and the daily total vehicle trips in a study area is shown in Figure 7.

Intrazonal Central Business District Vehicle Trips

The intrazonal central business district vehicle trips are those movements that have both their origin and destination within that particular delimited zone. The length of these trips are necessarily very short due to the small area of the district, which was less than one square mile for all the study locations. Both the freeway and its interchanges should be located to discourage freeway usage by these trips because short trips decrease the efficiency of the facilities in that more weaving is performed within a short distance where the freeway volume is highest.

TABLE 14

ANALYSIS OF VARIANCE FOR VEHICLE TRIPS TO AND FROM THE CENTRAL BUSINESS DISTRICT

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	5	131.755×10^8	26.351×10^8	27.12
Deviation About Regression	8	7.774×10^8	$.972 \times 10^8$	
Total	13	139.529×10^8		

TABLE 15

COMPARISON OF TRUE AND ESTIMATED TRIPS TO AND FROM THE CENTRAL BUSINESS DISTRICT

City	Actual Trips to & From the CBD	Estimated Trips to & From the CBD	Residual
Charlotte	87376	84822	2554
Chattanooga	46627	43262	3365
Dayton	104859	111563	-6704
Denver	118844	120155	-1311
El Paso	49448	41424	8024
Huntsville	22855	37499	-14644
Nashville	68604	74252	-5648
New Orleans	119640	123153	-3513
Omaha	62879	65733	-2854
San Antonio	115507	102682	12825
Springfield	37395	29113	8277
Toledo	59773	65042	-5269
Tucson	42768	47698	-4930
Tulsa	93214	83386	9828

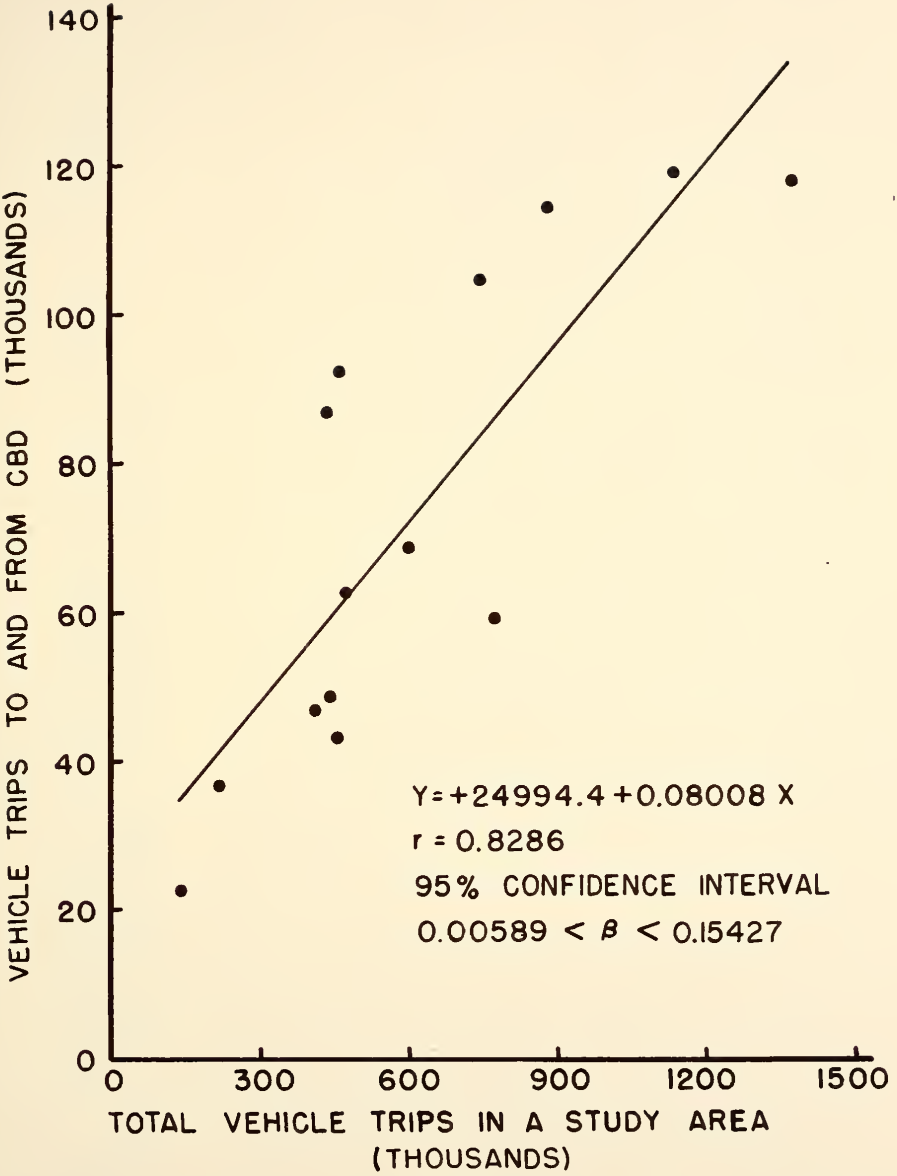


FIG. 7 RELATION BETWEEN VEHICLE TRIPS TO AND FROM CBD AND TOTAL VEHICLE TRIPS

TABLE 16

SIMPLE CORRELATION COEFFICIENTS FOR TRIPS TO AND FROM THE CENTRAL BUSINESS DISTRICT

X_1 = TRANSPORTATION STUDY POPULATION

X_2 = AREA OF CBD

X_3 = POPULATION DENSITY

X_4 = TRANSPORTATION STUDY AREA

X_5 = PERCENT USING PUBLIC TRANSPORTATION TO WORK

X_6 = PERCENT UNITS WITH ONE AUTOMOBILE

X_7 = PERCENT OF WHITE COLLAR WORKERS

X_8 = MEDIAN INCOME OF FAMILIES

$Y = X_9$ = VEHICLE TRIPS

$X_{10} = X_1 X_2$

$X_{11} = X_2 X_3$

$X_{12} = X_1^2$

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	$Y = X_9$	X_{10}	X_{11}	X_{12}
X_1	1.000											
X_2	.590	1.000										
X_3	.558	.410	1.000									
X_4	.376	.079	-.396	1.000								
X_5	.621	.616	.511	-.045	1.000							
X_6	-.556	-.723	.033	-.383	-.551	1.000						
X_7	.374	.144	-.004	.347	-.006	-.339	1.000					
X_8	.099	.051	.290	.009	-.200	.289	.180	1.000				
Y = X_9	.822	.812	.662	.131	.511	-.546	.377	.131	1.000			
X_{10}	.947	.744	.521	.292	.712	-.646	.303	.052	.847	1.000		
X_{11}	.719	.828	.795	-.093	.701	-.410	.076	.143	.880	.816	1.000	
X_{12}	.972	.541	.477	.362	.614	-.576	.383	.066	.763	.956	.667	1.000

These daily trips ranged from 1790 in Tucson to 13976 in New Orleans. To evolve the following univariate prediction model thirteen subsets containing various combinations of eleven independent variables were used.

$$\begin{aligned} Y &= + 5790 + 6406.7\ X_2 + 0.8432\ X_3 \\ &\quad - 1.18459\ X_4 - 0.00017\ X_{10} + 0.01909\ X_{13} \end{aligned} \qquad \text{(V)}$$

where:

Y = intrazonal central business district trips per day

X_2 = area of the central business district in square miles

X_3 = transportation study population density

X_4 = median family income for the standard metropolitan statistical area

X_{10} = interaction of transportation study population by the percent of employed persons using public transportation to work

X_{13} = interaction of the transportation study population by the area of the central business district

The amount of variability (R^2) explained by this model is 98.5 percent. Table 17 shows the analysis of variance and the true, estimated, and residual of the intrazonal central business district trips are shown in Table 18. The simple correlation coefficients between the various variables are shown in Table 19, and the relationship between intrazonal vehicle trips per day and total vehicle trips in a study area is shown in Figure 8 .

Study Zones

For the evolution of models for the number of vehicle trips per day attracted to and generated by a zone, the number of vehicle trips per day in both directions between a zone and the central business district, and the number of interzonal vehicle trips per day, 75 study zones, excluding

TABLE 17

ANALYSIS OF VARIANCE FOR INTRAZONAL CENTRAL BUSINESS DISTRICT TRIPS

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	5	2000.1×10^5	400.0×10^5	101.8
Deviation About Regression	8	31.4×10^5	3.93×10^5	
Total	13	2031.5×10^5		

TABLE 18

COMPARISON OF INTRAZONAL CENTRAL BUSINESS DISTRICT TRIPS

Location	Intrazonal Vehicle Trips	Estimated Intrazonal Vehicle Trips	Residual
Charlotte	7807	7546	261
Chattanooga	4384	4723	-339
Dayton	9048	8568	480
Denver	10403	10702	-299
El Paso	2330	2293	37
Huntsville	636	1222	-586
Nashville	7527	7534	-7
New Orleans	13976	13958	18
Omaha	3900	4099	-199
San Antonio	10203	9787	416
Springfield	2384	1331	1053
Toledo	3571	3807	236
Tucson	1790	1481	309
Tulsa	4670	5578	908

TABLE 19

SIMPLE CORRELATION COEFFICIENTS FOR INTRAZONAL CENTRAL BUSINESS DISTRICT TRIPS

X_1 = TRANSPORTATION STUDY POPULATION
X_2 = AREA OF CBD
X_3 = TRANSPORTATION STUDY POPULATION DENSITY
X_4 = MEDIAN FAMILY INCOME
X_5 = UNITS WITH ONE AUTOMOBILE
X_6 = PERCENT USING PUBLIC TRANSPORTATION
X_7 = PERCENT WHITE COLLAR WORKERS
X_8 = TOTAL VEHICLE TRIPS
$Y=X_9$ = INTRAZONAL VEHICLE TRIPS
$X_{10} = X_1 X_6$
$X_{11} = X_1^2$
$X_{12} = X_2 X_{11}$
$X_{13} = X_1 X_2$

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	$Y=X_9$	X_{10}	X_{11}	X_{12}	X_{13}
X_1	1.000												
X_2	.590	1.000											
X_3	.558	.410	1.000										
X_4	.099	.051	.290	1.000									
X_5	-.554	-.723	.033	.289	1.000								
X_6	.621	.616	.511	-.200	-.551	1.000							
X_7	.374	.144	-.004	.180	-.339	-.006	1.000						
X_8	.975	.596	.536	.242	-.545	.501	.412	1.000					
$Y=X_9$	.857	.876	.576	-.025	-.654	.699	.191	.820	1.000				
X_{10}	.802	.552	.525	-.147	-.545	.901	.113	.678	.769	1.000			
X_{11}	.972	.541	.477	.066	-.576	.614	.383	.929	.827	.837	1.000		
X_{12}	.935	.589	.454	.025	-.605	.685	.327	.869	.845	.894	.984	1.000	
X_{13}	.947	.744	.521	.052	-.647	.712	.303	.900	.939	.869	.956	.971	1.000

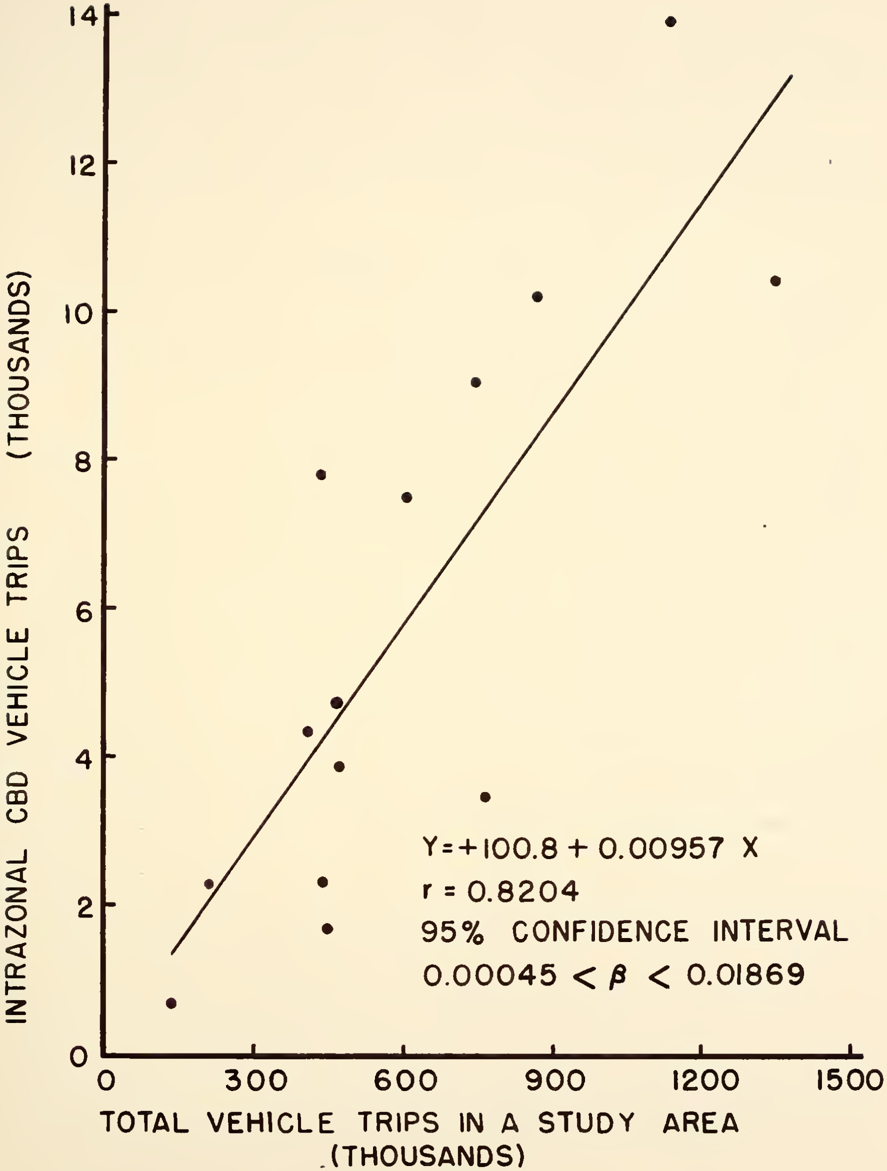


FIG. 8 RELATION BETWEEN INTRAZONAL CBD TRIPS AND TOTAL TRIPS

the central business district, were chosen from thirteen study cities. These were chosen on the basis of being representative of the entire study area. This number of zones was chosen for the following reasons:

a. A minimum of two zones per city is required for an analysis of interzonal trips.

b. It was desired to weight the samples according to the transportation study population.

c. The maximum number of variables to be considered was estimated to be about 60, and therefore sample size larger than 60 was required for the statistical analysis.

Analyses, therefore, were made on the vehicle trips attracted to and generated by 75 zones, the vehicle trips in both directions between those 75 zones and their respective central business districts, and the interzonal vehicle trips within the cities. The resulting number of interchanges was 269. Table 20 shows the cities, number of zones, and zonal interchanges.

The origin and destination zones and the census tracts coincided only in the Tucson metropolitan area. Figures A-1 through A-26 in Appendix A show the transportation study area and the tracted census area for each study city. The shaded origin and destination zones are the sample study zones.

The data collected for evolving models for vehicle trips attracted to and generated by a zone, vehicle trips in both directions between a zone and the central business district, and the interzonal vehicle trips are shown in Table 21, and a more detailed description of these data follows:

a. Origin and destination zone number. This is the number or numbers assigned to each study zone by the agency who performed the transportation study.

b. Population of each study zone was obtained from the transportation study for all cities except Dayton, Springfield, Toledo, and Tulsa where it came from the census.

TABLE 20

STUDY ZONES

City	No. of Zones	No. of Zonal Interchanges
Charlotte	3	3
Chattanooga	4	6
Dayton	2	1
Denver	13	78
El Paso	4	6
Nashville	5	10
New Orleans	14	91
Omaha	5	10
San Antonio	9	36
Springfield	2	1
Toledo	6	15
Tucson	4	6
Tulsa	4	6
Total	75	269

TABLE 21
STUDY ZONE DATA

	ORIGIN AND DESTINATION ZONE NUMBER	ZONE POPULATION	STRAIGHT LINE DISTANCE FROM CBD (MILES)	AREA OF ZONE (MILES^2)	POPULATION DENSITY PERSONS PER MILE^2	PERCENT WHITE POPULATION	POPULATION PER HOUSEHOLD	PERCENT ENROLLED IN SCHOOL	INCOME LESS THAN $ 6000 — PERCENT	INCOME $ 6000 - $ 10 000 — PERCENT	INCOME GREATER THAN $10000 — PERCENT	FAMILY MEDIAN INCOME	PERCENT WORKERS
CHARLOTTE	223	1843	0.57	0.40	4573	70.76	3.16	18.92	79.41	13.96	6.63	3677	42.13
	623	6346	3.29	1.25	5073	99.94	3.41	22.39	49.08	41.97	8.95	6053	42.87
	832	3173	4.08	2.39	1326	99.72	3.29	25.98	17.84	22.78	59.38	11881	38.41
CHATTANOOGA	532	6222	0.74	0.64	9617	37.51	2.75	21.15	86.75	10.57	2.68	3188	37.99
	574	6911	2.80	0.96	7147	32.44	3.73	26.31	75.77	19.49	4.74	4156	32.79
	662	615	8.32	2.12	289	88.59	3.70	23.11	65.28	29.01	5.71	4755	30.66
	825	2862	3.60	1.22	2331	99.08	3.16	21.38	52.41	37.07	10.52	5870	39.32
DAYTON	125	4174	1.68	0.98	4238	94.34	2.74	27.24	52.01	32.21	15.78	5520	43.84
	215 216	5274	1.59	1.50	3511	99.98	3.34	23.53	71.25	23.92	4.83	4188	27.47
DENVER	151	16900	5.57	6.76	2497	98.92	4.00	26.06	35.23	48.32	16.45	6983	34.74
	312	13000	0.74	0.33	38922	98.15	1.57	6.49	66.53	26.71	6.76	4638	55.19
	322	12300	1.88	0.74	16422	42.30	3.50	24.85	68.23	24.61	7.16	4834	36.24
	325	12500	1.84	1.07	11682	98.57	2.38	13.81	47.82	24.69	27.49	7424	48.47
	341	5900	3.89	1.28	4595	95.26	3.46	23.85	32.22	46.38	21.40	7456	38.94
	342	15700	3.88	2.08	7523	96.71	3.24	26.19	25.97	42.81	31.22	7442	39.69
	345	12900	4.12	1.75	7363	99.28	3.46	31.14	17.40	16.94	65.66	14037	34.65
	364	7700	7.36	1.15	6696	99.34	3.48	23.45	52.98	37.55	9.47	5811	38.92
	532	12800	2.76	1.68	7596	98.38	3.37	25.09	52.77	34.07	13.16	5879	36.59
	554	7600	5.62	3.38	2246	99.83	3.59	31.15	26.62	39.86	33.52	8381	37.04

TABLE 21 (CONT.)

	ORIGIN AND DESTINATION ZONE NUMBER	PERCENT USING CAR TO WORK	PERCENT EMPLOYED IN SMSA	PERCENT EMPLOYED IN MANUFACTURING	PERCENT EMPLOYED IN WHOLESALE	PERCENT EMPLOYED IN RETAIL	MEDIAN HOUSE VALUE	NUMBER OF PASSENGER CARS	PERSONS PER CAR	EXTERNAL VEHICLE TRIPS	INTERNAL VEHICLE TRIPS	ZONE - CBD VEHICLE TRIPS	TOTAL VEHICLE TRIPS
CHARLOTTE	223	19.81	38.79	8.34	1.64	7.78	8400	400	4.61	1008	7229	1272	8237
	623	35.90	39.34	12.07	2.87	7.07	10900	2284	2.78	1289	14297	1631	15586
	832	34.71	33.97	8.54	5.25	3.66	25000	1699	1.87	474	9722	1413	10196
CHATTANOOGA	532	13.55	33.95	8.74	0.76	3.95	9500	1240	5.02	1346	17767	2490	18113
	574	18.37	29.98	10.60	0.84	3.15	7400	795	8.69	522	7459	510	7981
	662	26.77	29.10	10.04	0.28	3.84	7300	276	2.23	71	1320	74	1391
	825	31.94	37.10	12.01	1.27	6.19	10200	1124	2.55	296	6417	569	6713
DAYTON	125	15.96	39.48	17.61	0.57	4.00	10000	1109	3.76	7401	27106	1972	34507
	215 216	15.68	25.65	11.89	0.51	3.15	9500	1041	5.07	6073	33337	2596	39410
DENVER	151	31.26	32.54	8.42	1.61	5.17	14600	7275	2.32	1439	44699	1680	46138
	312	15.65	46.70	6.24	0.84	2.35	16500	2567	5.06	891	32408	3258	33299
	322	22.13	32.73	5.47	0.74	3.88	8700	2955	4.16	335	18302	757	18637
	325	25.23	41.82	6.00	2.68	5.62	20100	3821	3.27	513	25302	2349	25815
	341	33.08	37.21	6.37	3.31	5.25	14800	3571	1.65	351	20643	1350	20994
	342	31.49	38.32	5.31	2.93	6.36	14800	7254	2.16	778	39854	3235	40632
	364	32.58	37.51	4.74	1.46	5.36	12500	2944	2.62	831	20324	352	21155
	532	27.80	34.05	8.05	2.00	5.63	11100	3976	3.22	357	25944	1034	26301
	554	33.46	35.09	6.24	1.46	5.26	19400	3026	2.51	357	19913	882	20270
	345	28.70	32.27	4.81	3.53	5.75	25000	4927	2.62	430	24948	2003	25378

TABLE 21 (CONT.)

	ORIGIN AND DESTINATION ZONE NUMBER	ZONE POPULATION	STRAIGHT LINE DISTANCE FROM CBD (MILES)	AREA OF ZONE (MILES^2)	POPULATION DENSITY PERSONS PER MILE^2	PERCENT WHITE POPULATION	POPULATION PER HOUSEHOLD	PERCENT ENROLLED IN SCHOOL	INCOME LESS THAN \$ 6 000— PERCENT	INCOME \$ 6 000- \$ 10 000— PERCENT	INCOME GREATER THAN \$10 000 — PERCENT	FAMILY MEDIAN INCOME	PERCENT WORKERS
DENVER (CONT.)	633	11000	2.27	1.07	10280	96.93	3.32	24.43	51.06	32.12	16.82	5748	36.07
	641	9700	3.94	2.02	4802	99.17	3.08	22.82	43.05	41.79	15.16	6422	41.38
	642	16500	4.26	3.41	4837	99.84	3.20	25.21	33.74	46.83	19.43	7351	40.42
EL PASO	30	73400	2.68	1.34	5465	99.14	3.23	21.54	53.00	28.93	18.07	5822	39.61
	37	6257	3.32	0.74	8467	94.57	3.61	24.46	49.85	30.23	19.92	5883	37.18
	54	11734	8.14	2.32	5064	89.05	4.55	29.61	55.34	37.48	7.18	5719	31.12
	71	14609	7.94	2.46	5927	98.27	3.98	26.77	54.67	36.22	9.11	5676	31.03
NASHVILLE	535	5654	1.83	0.52	10957	3.43	3.87	35.10	85.89	11.90	2.21	3090	34.05
	541	1604	0.60	0.42	3739	0.57	2.87	17.29	89.26	8.37	2.37	2816	40.49
	644	4090	7.02	3.16	1294	95.98	3.60	24.27	20.25	52.60	27.15	8200	35.62
	715	4765	1.98	0.94	5058	98.00	3.38	22.65	55.96	36.57	7.49	5679	38.44
	861	1352	5.36	1.84	735	95.37	3.56	21.34	51.96	35.68	12.36	5876	38.67
NEW ORLEANS	10	40430	2.14	2.68	15075	80.83	3.31	22.97	70.59	25.83	3.58	4496	33.52
	14	52234	2.05	3.12	16720	66.72	3.10	21.50	69.79	22.27	7.94	4796	36.93
	22	69666	1.99	2.72	25537	30.68	2.95	20.70	77.58	15.32	7.10	4015	37.00
	32	14866	6.36	5.70	2604	75.96	3.77	26.88	47.66	38.94	13.40	6382	31.20
	41	12548	4.68	5.92	2116	84.13	3.97	29.10	42.88	37.31	19.81	6721	30.74
	50	10803	4.41	2.24	4823	98.70	3.90	28.51	40.40	47.55	12.05	6535	32.13
	52	0	6.20	4.26	0	0	0	0	0	0	0	0	0

TABLE 21 (CONT.)

	ORIGIN AND DESTINATION ZONE NUMBER	PERCENT USING CAR TO WORK	PERCENT EMPLOYED IN SMSA	PERCENT EMPLOYED IN MANUFACTURING	PERCENT EMPLOYED IN WHOLESALE	PERCENT EMPLOYED IN RETAIL	MEDIAN HOUSE VALUE	NUMBER OF PASSENGER CARS	PERSONS PER CAR	EXTERNAL VEHICLE TRIPS	INTERNAL VEHICLE TRIPS	ZONE - CBO VEHICLE TRIPS	TOTAL VEHICLE TRIPS
DENVER (CONT.)	633	26.05	34.29	8.82	2.83	5.74	11000	2591	4.24	410	17816	716	18226
	641	33.68	36.76	8.22	1.95	5.13	12600	3762	2.58	832	40242	1388	41074
	642	33.44	36.54	7.55	3.00	6.38	16300	7236	2.28	1164	55875	1993	57039
EL PASO	30	28.98	37.67	4.68	2.43	6.62	12300	2629	2.79	708	17979	1305	18687
	37	28.59	35.08	4.57	1.44	5.96	12000	1601	3.91	713	14024	734	14737
	54	25.88	29.88	5.22	1.14	3.72	10600	3260	3.60	694	14195	750	14889
	71	26.62	27.26	2.86	0.71	3.78	11500	3834	3.81	682	26564	660	27246
NASHVILLE	535	15.44	32.39	4.97	1.04	2.37	7100	905	6.25	157	6101	412	6258
	541	8.68	38.22	7.12	1.52	2.23	6200	171	9.38	1558	12070	1287	13628
	644	32.31	33.46	7.86	3.78	3.90	16300	1676	2.44	322	7331	626	7653
	715	30.62	34.76	9.44	3.62	4.97	9600	1080	4.41	533	7273	674	7806
	861	32.20	36.19	11.55	2.10	5.40	10900	575	2.35	134	2971	150	3105
NEW ORLEANS	10	15.09	33.32	6.21	1.93	5.99	10900	8340	4.85	1407	87930	5402	89337
	14	14.72	33.44	5.11	2.12	5.66	14000	10896	4.79	1863	120662	7659	122525
	22	11.31	33.27	3.73	2.04	4.13	15600	11678	5.96	1644	117785	8508	119429
	32	22.01	29.18	5.33	1.54	4.52	16400	4170	3.56	680	24905	1202	25585
	41	21.35	27.71	4.67	1.38	2.87	15900	3637	3.45	399	24990	560	25389
	50	26.51	30.56	9.36	1.48	2.87	15600	3271	3.30	933	29781	1163	30714
	52	0	0	0	0	0	0	0	0	4	40	0	44

TABLE 21 (CONT.)

	ORIGIN AND DESTINATION ZONE NUMBER	ZONE POPULATION	STRAIGHT LINE DISTANCE FROM CBD (MILES)	AREA OF ZONE (MILES²)	POPULATION DENSITY PERSONS PER MILE²	PERCENT WHITE POPULATION	POPULATION PER HOUSEHOLD	PERCENT ENROLLED IN SCHOOL	INCOME LESS THAN $ 6 000— PERCENT	INCOME $ 6 000- $ 10 000— PERCENT	INCOME GREATER THAN $ 10 000 —— PERCENT	FAMILY MEDIAN INCOME	PERCENT WORKERS
NEW ORLEANS (CONT.)	62	14819	5.30	5.36	2762	52.47	4.14	28.12	74.64	21.96	3.40	4296	28.61
	64	5906	5.23	8.22	719	78.43	3.76	26.81	60.51	30.11	9.30	5181	31.67
	72	6830	5.88	2.68	2547	99.86	3.85	25.82	28.33	45.12	26.55	7641	32.23
	75	20239	9.27	4.54	4456	99.86	3.85	25.82	28.33	45.12	26.55	7641	32.23
	77	8905	8.37	2.18	4087	84.10	4.09	26.92	39.76	42.12	18.12	6758	31.62
	79	6042	4.60	1.81	3331	74.78	3.29	24.14	51.36	27.94	20.70	6161	36.90
	80	1989	7.76	5.56	358	82.27	4.09	27.51	64.85	29.24	5.91	4892	25.98
OMAHA	23	13530	4.28	2.19	6172	99.86	3.41	25.47	35.47	44.56	20.04	6999	38.80
	45	800	5.72	2.62	306	99.89	3.55	25.77	35.78	47.46	16.76	6991	38.29
	51	15688	2.34	1.60	9805	99.71	2.87	23.38	25.70	27.04	47.26	6857	46.51
	76	585	5.50	1.11	526	100.00	4.13	33.12	23.68	50.00	26.32	8569	31.21
	84	12132	4.05	1.84	6565	91.00	3.56	24.75	51.23	36.47	12.30	5675	35.84
SAN ANTONIO	11	15033	1.46	1.34	11185	98.67	2.41	16.74	66.79	21.12	12.09	4414	45.36
	16	10140	6.29	7.40	1370	99.66	3.12	24.57	28.86	34.90	36.24	8330	21.39
	33	8969	3.02	1.49	6003	69.15	3.65	23.34	78.09	17.97	3.94	3913	33.91
	44	22629	4.38	3.69	6133	99.25	4.38	27.37	79.86	17.27	2.87	4237	26.81
	53	7940	3.25	1.23	6440	99.76	5.03	32.22	81.44	16.30	2.26	4190	23.15
	61	28443	2.32	2.02	14046	79.95	3.74	25.91	84.57	13.28	2.15	3358	30.52
	67	1958	6.64	2.90	676	89.22	3.70	28.61	50.39	29.18	20.43	5957	36.21

TABLE 21 (CONT.)

	ORIGIN AND DESTINATION ZONE NUMBER	PERCENT USING CAR TO WORK	PERCENT EMPLOYED IN SMSA	PERCENT EMPLOYED IN MANUFACTURE	PERCENT EMPLOYED IN WHOLESALE	PERCENT EMPLOYED IN RETAIL	MEDIAN HOUSE VALUE	NUMBER OF PASSENGER CARS	PERSONS PER CAR	EXTERNAL VEHICLE TRIPS	INTERNAL VEHICLE TRIPS	ZONE - CBO VEHICLE TRIPS	TOTAL VEHICLE TRIPS
NEW ORLEANS (CONT.)	62	15.89	27.61	14.13	1.52	3.21	10200	2825	5.24	919	25485	403	26404
	64	22.11	30.06	8.42	2.50	4.71	1400	1383	4.27	1122	21817	305	22939
	72	28.43	29.78	6.52	2.33	4.75	21000	2533	2.70	227	20642	706	20869
	75	28.43	29.78	6.52	2.33	4.75	21000	6820	2.97	1345	47521	1681	48866
	77	25.90	28.89	6.39	1.93	4.33	16700	2877	3.10	476	15981	331	16457
	79	24.62	35.32	5.22	2.24	4.97	16300	1953	3.09	1132	26293	1507	27425
	80	18.78	23.38	7.34	0.57	2.26	11800	680	2.92	889	6439	53	7328
OMAHA	23	28.62	37.17	7.33	2.57	5.52	12100	4218	3.21	1019	24342	1999	25361
	45	29.29	36.50	7.10	2.60	5.13	15400	232	3.45	184	1832	31	2016
	51	30.82	43.63	6.23	2.57	9.41	13400	5176	3.03	1894	39554	4218	41448
	76	26.11	31.21	2.55	2.55	1.91	19100	169	3.46	53	991	62	1044
	84	22.40	34.61	15.40	0.91	3.42	9600	2718	4.46	1062	18649	775	19711
SAN ANTONIO	11	28.51	40.84	4.28	2.22	7.31	11300	5606	2.68	1585	47280	6322	48865
	16	33.37	35.08	3.00	2.30	5.02	17600	4616	2.20	2223	27409	2934	29632
	33	22.23	31.95	2.61	1.05	4.46	6600	2363	3.80	402	13210	1017	13612
	44	20.72	25.41	4.01	1.09	3.82	6600	5732	3.95	936	39606	1332	40542
	53	17.62	22.01	3.22	0.88	2.61	7100	1970	4.03	123	10086	830	10209
	61	18.10	29.44	4.32	1.22	4.41	6000	5265	5.40	777	35341	2917	36118
	67	24.09	27.97	3.78	3.13	4.47	12000	755	2.59	371	3131	270	3502

TABLE 21 (CONT.)

	ORIGIN AND DESTINATION ZONE NUMBER	ZONE POPULATION	STRAIGHT LINE DISTANCE FROM CBD (MILES)	AREA OF ZONE (MILES^2)	POPULATION DENSITY PERSONS PER MILE^2	PERCENT WHITE POPULATION	POPULATION PER HOUSEHOLD	PERCENT ENROLLED IN SCHOOL	INCOME LESS THAN \$ 6 000— PERCENT	INCOME \$ 6 000 - \$ 10 000— PERCENT	INCOME GREATER THAN \$10 000 — PERCENT	FAMILY MEDIAN INCOME	PERCENT WORKERS
SAN ANTONIO (CONT.)	71	10373	2.65	1.29	8022	99.45	2.61	17.42	55.28	29.95	14.77	5531	42.72
	73	7684	4.48	1.55	4945	99.58	3.14	27.18	35.51	37.57	26.92	7393	40.30
SPRINGFIELD	120	3889	0.64	0.23	16909	51.27	3.08	21.86	67.63	27.61	4.76	4770	36.87
	206	1393	1.92	0.95	14617	98.78	3.35	25.50	44.84	39.94	15.22	6471	37.04
TOLEDO	103	3440	0.66	0.19	17732	57.97	2.45	21.28	84.82	12.59	2.59	3154	36.02
	105	2162	1.12	0.27	7949	16.05	3.49	24.74	78.96	17.08	3.96	3397	26.64
	127	4477	2.62	0.81	5500	86.58	3.32	24.88	47.38	40.65	11.97	6205	38.51
	146	3255	4.64	0.91	3577	100.00	3.13	28.79	33.67	45.97	20.36	6481	37.42
	150	5254	5.57	4.35	1208	99.94	3.61	26.82	28.89	44.09	27.02	7424	36.41
	232	4340	2.38	0.74	5873	94.45	3.40	26.61	48.06	37.91	14.03	6142	29.45
TUCSON	5	8189	1.14	0.88	9211	98.56	2.18	54.17	65.20	22.35	12.45	5024	33.27
	13	9711	2.04	1.66	5864	96.83	2.70	20.50	71.06	25.12	3.82	4667	37.58
	23	6906	1.89	0.98	6990	88.41	3.53	26.26	84.46	13.88	1.66	3776	26.34
	36	15493	5.34	3.32	4671	99.42	3.83	25.92	51.46	37.25	11.29	5907	32.94
TULSA	340	1876	2.20	0.50	3767	97.25	2.85	22.11	33.29	43.47	23.24	7490	44.98
	421 422	2631	3.81	2.60	1010	3.67	3.69	29.32	92.34	5.34	2.31	2660	29.89
	503	3746	1.34	0.48	7870	98.53	2.11	13.97	54.07	32.54	13.39	5634	51.62
	623 624	3369	3.34	1.42	2378	98.74	3.19	30.40	7.96	11.47	80.57	19615	34.08

TABLE 21 (CONT.)

	ORIGIN AND DESTINATION ZONE NUMBER	PERCENT USING CAR TO WORK	PERCENT EMPLOYED IN SMSA	PERCENT EMPLOYED IN MANUFACTURE	PERCENT EMPLOYED IN WHOLESALE	PERCENT EMPLOYED IN RETAIL	MEDIAN HOUSE VALUE	NUMBER OF PASSENGER CARS	PERSONS PER CAR	EXTERNAL VEHICLE TRIPS	INTERNAL VEHICLE TRIPS	ZONE – CBD VEHICLE TRIPS	TOTAL VEHICLE TRIPS
SAN ANTONIO (CONT.)	71	32.48	40.13	3.76	2.39	7.39	9800	4101	2.53	1135	30288	3230	31423
	73	35.01	38.31	4.81	2.91	7.25	13100	3378	2.27	777	24149	1735	24926
SPRINGFIELD	120	24.56	28.28	11.11	0.39	8.47	8900	985	3.95	855	7276	816	8131
	206	27.71	31.51	16.01	0	3.59	12200	459	3.03	303	1536	150	1840
TOLEDO	103	13.60	32.38	6.28	0.99	0.70	10300	686	5.01	2222	19963	2001	22185
	105	14.85	23.64	6.15	1.30	1.99	7400	334	6.47	896	8362	494	9258
	127	28.72	35.76	17.31	1.01	4.04	11400	1413	3.17	580	7246	292	7826
	146	29.49	35.30	12.66	2.18	6.14	16200	624	5.22	1232	18457	429	19689
	150	31.37	32.81	14.18	1.73	5.22	15400	1844	2.85	1064	11451	341	12515
	232	22.76	26.06	11.77	1.45	3.18	10800	1231	3.52	1308	8026	336	9334
TUCSON	5	17.67	30.72	1.55	0.87	4.59	12100	3152	2.60	423	44253	2398	44676
	13	27.50	34.41	4.06	0.80	5.80	8600	3863	2.51	1367	32443	2214	33810
	23	19.70	24.86	2.94	0.63	3.54	5500	1674	4.12	516	16411	1290	16927
	36	29.78	31.53	5.08	1.24	5.09	11000	5303	2.92	342	46308	1349	46650
TULSA	340	34.59	42.67	8.30	2.98	7.11	11000	900	2.08	376	5010	941	5386
	421 422	19.09	26.92	1.84	0.09	4.15	5000	579	4.54	277	4029	249	4306
	503	29.47	46.15	8.07	2.82	8.03	10800	1819	2.06	1423	21020	2644	22443
	623 624	28.52	31.88	6.92	1.86	3.19	25000	2282	1.48	568	10302	1471	21172

c. Straight line distance from the centroid of the central business district to the centroid of each study zone in miles.

d. Area of each study zone in square miles.

e. Population density of each study zone in persons per square mile.

f. Percent of white population was obtained by dividing the number of white people by the total number of people for the census tract.

g. Population per household was obtained by dividing the population in households, that is, persons who occupy a housing unit, by the number of housing units in the census tract.

h. Percent of population enrolled in school was obtained by dividing the total number of persons 5 to 34 years old enrolled in school by the total number of people for the census tract.

i. Percent of families whose income was less than $6000 in 1959 was obtained by dividing the number of families in this income bracket by the total number of families in the census tract.

j. Percent of families whose income in 1959 was between $6000 and $10,000 was obtained by dividing the number of families in this income bracket by the total number of families in the census tract.

k. Percent of families whose income was greater than $10,000 in 1959 was obtained by dividing the number of families in this income bracket by the total number of families in the census tract.

l. Median income of families in the census tract in 1959.

m. Percent of population that were workers was obtained by dividing the number of workers, including armed forces, by the population of the census tract.

n. Percent of population that used a car to work was obtained by dividing the number of workers including armed forces that used a private automobile or car pool to work by the population of the census tract.

o. Percent of population that worked inside the standard metropolitan statistical area was obtained by dividing the number that worked in the statistical area by the population of the census tract.

p. Percent of population employed in manufacturing was obtained by dividing the number employed in manufacturing by the population of the census tract.

q. Percent of population employed in wholesale trade was obtained by dividing the number employed in wholesale trade by the population of the census tract.

r. Percent of population employed in retail trade was obtained by dividing the number employed in retail trade by the population of the census tract.

s. Median dollar value of house was the estimate given by the respondent in the census for how much the property would sell in April, 1960. Value data were restricted to owner-occupied units having only one housing unit in the property and no business.

t. Number of passenger cars that were owned by the population of each zone.

u. Number of persons per passenger car was obtained by dividing the population of the zone by the number of passenger cars that were owned in each zone.

v. Number of external vehicle trips per day that were attracted to or generated by each zone.

w. Number of internal vehicle trips per day that were attracted to or generated by each zone.

x. Number of vehicle trips per day in both directions between each study zone and the central business district.

y. Total number of vehicle trips per day, that is, internal and external that were attracted to and generated by each zone.

The number of vehicle trips between the various zones for each study location is above the diagonal and the distance in miles from centroid to centroid between the various zones is shown below the diagonal in Table 22. The angle less than 180° between the centroids of the study zones with the vertex at the centroid of the central business is shown in Table 23.

In addition, data that were previously tabulated concerning the entire study area were used.

TABLE 22

VEHICLE TRIPS AND DISTANCES BETWEEN ZONES

STUDY CITY

ORIGIN AND DESTINATION ZONE NUMBER

ORIGIN AND DESTINATION ZONE NUMBER	1	2	. . .
1	—	VEHICLE TRIPS PER DAY	
2	STRAIGHT LINE DISTANCE – MI.	—	
⋮			—

DAYTON

	125	215 & 216
125	—	400
215 & 216	3.17	—

SPRINGFIELD

	120	206
120	—	10
206	2.54	—

CHARLOTTE

	223	623	832
223	—	72	32
623	7.28	—	11
832	4.66	4.97	—

CHATTANOOGA

	532	574	662	825
532	—	107	42	134
574	3.07	—	0	17
662	7.72	8.34	—	0
825	3.54	6.38	9.94	—

TABLE 22 (CONT.)

DENVER

	151	312	322	325	341	342	345	364	532	554	633	641	642
151	—	313	162	78	48	209	0	148	230	54	648	409	1745
312	6.02	—	178	955	232	542	352	142	240	185	235	163	610
322	5.19	1.58	—	157	167	208	181	0	12	0	50	153	87
325	7.22	1.22	2.40	—	75	470	446	33	121	160	55	51	17
341	6.60	3.32	2.18	3.44	—	2613	230	140	38	0	0	84	147
342	7.23	3.21	2.44	3.06	0.78	—	514	104	0	146	0	311	277
345	8.98	3.38	3.78	2.36	3.30	2.54	—	89	84	16	59	0	30
364	10.94	6.60	6.20	5.90	4.34	3.98	4.25	—	81	37	0	101	48
532	6.56	3.34	4.61	3.88	6.63	6.58	6.18	9.78	—	95	80	946	467
554	7.65	6.26	7.36	6.84	9.48	9.48	9.12	12.74	2.98	—	12	1363	397
633	3.36	2.82	2.60	4.04	4.68	5.02	6.09	8.81	3.54	5.59	—	824	824
641	5.64	4.66	5.48	5.50	7.66	7.77	7.86	11.28	1.98	2.12	3.48	—	2838
642	4.24	5.00	5.38	6.05	7.53	7.80	8.37	11.50	3.22	3.43	2.92	1.56	—

TABLE 22 (CONT.)

NASHVILLE

	535	541	644	715	861
535	—	127	0	26	0
541	1.58	—	0	66	40
644	7.51	8.23	—	16	0
715	3.14	2.58	5.08	—	30
861	6.35	5.04	11.86	6.90	—

OMAHA

	23	45	51	76	84
23	—	38	769	0	106
45	3.34	—	58	0	32
51	3.60	3.64	—	22	275
76	7.44	5.88	4.04	—	0
84	8.08	8.34	4.83	4.48	—

SAN ANTONIO

	11	16	33	44	53	61	67	71	73
11	—	641	70	123	25	654	46	2181	810
16	5.15	—	0	21	0	133	41	265	133
33	3.98	6.82	—	80	20	123	0	10	0
44	5.66	10.66	5.36	—	151	246	0	31	41
53	3.98	9.10	5.70	2.80	—	540	21	82	103
61	2.24	7.14	5.34	4.59	2.13	—	103	225	295
67	6.12	9.62	9.69	7.74	5.02	4.36	—	62	143
71	1.48	5.42	5.43	6.25	3.98	1.86	4.82	—	1553
73	3.40	6.26	7.34	7.42	4.76	2.85	3.36	1.92	—

TABLE 22 (CONT.)

NEW ORLEANS

	10	14	22	32	41	50	52	62	64	72	75	77	79	80
10	—	3809	1301	1358	158	2098	20	33	75	266	336	145	286	42
14	2.73	—	3493	1459	87	356	0	144	185	760	761	214	578	80
22	4.15	2.87	—	261	79	262	0	106	87	400	717	237	996	0
32	4.36	5.68	8.18	—	74	191	0	0	42	23	102	87	75	20
41	4.10	6.41	6.08	7.25	—	0	0	83	493	0	66	37	118	442
50	2.77	5.48	6.28	4.90	2.38	—	0	9	31	40	46	22	116	51
52	4.22	6.86	8.16	4.18	4.10	2.07	—	0	0	0	0	0	0	0
62	7.36	6.56	3.68	11.66	7.52	8.77	10.78	—	1820	40	38	119	72	89
64	6.58	7.26	4.86	10.86	4.86	6.76	8.78	3.52	—	0	40	40	87	309
72	6.58	4.02	5.64	7.85	10.42	9.33	10.38	8.72	10.50	—	488	37	204	29
75	8.56	6.40	6.44	10.13	11.16	10.76	11.85	7.58	9.76	3.88	—	632	689	30
77	8.24	6.28	5.27	10.70	10.00	10.22	11.61	5.30	7.98	5.16	2.92	—	833	0
79	5.02	2.95	2.69	7.34	7.39	7.12	8.39	4.54	6.40	2.57	7.68	3.36	—	109
80	6.72	7.84	6.37	9.72	3.98	5.88	7.20	5.50	2.72	10.80	12.62	10.70	6.52	—

TABLE 22 (CONT.)

EL PASO

	30	37	54	71
30	—	288	182	242
37	1.76	—	415	121
54	7.15	5.41	—	116
71	5.26	5.62	8.57	—

TUCSON

	5	13	23	36
5	—	1428	364	930
13	2.00	—	333	464
23	2.50	3.90	—	206
36	4.59	6.45	5.26	—

TULSA

	340	421 & 422	503	623 & 624
340	—	21	131	41
421 & 422	2.97	—	61	42
503	3.23	3.76	—	653
623 & 624	5.38	5.54	2.18	—

TOLEDO

	103	105	127	146	150	232
103	—	157	122	140	132	36
105	0.93	—	48	42	53	21
127	2.60	5.52	—	71	15	28
146	4.03	4.50	4.06	—	71	21
150	5.03	4.54	7.08	4.70	—	10
232	3.02	3.36	3.22	6.66	7.90	—

TABLE 23
ANGLE BETWEEN ZONES

STUDY CITY

ORIGIN AND DESTINATION ZONE NUMBER

ORIGIN AND DESTINATION ZONE NUMBER	1	2	...
1	—	ANGLE WITH VERTEX AT CBD — DEGREE	
2		—	
⋮			—

DAYTON

	125	215 & 216
125	—	151
215 & 216		—

CHARLOTTE

	223	623	832
223	—	113	163
623		—	85
832			—

CHATTANOOGA

	532	574	662	825
532	—	98	21	82
574		—	77	180
662			—	103
825				—

TABLE 23 (CONT.)

DENVER

	151	312	322	325	341	342	345	364	532	554	633	641	642
151	—	123	68	149	81	98	135	115	98	86	9	70	49
312		—	56	25	38	26	12	9	137	151	133	166	172
322			—	81	18	30	67	47	167	154	77	138	117
325				—	62	51	14	34	114	125	157	142	163
341					—	11	49	29	176	173	95	156	135
342						—	37	17	164	176	107	168	147
345							—	20	127	139	143	155	177
364								—	147	159	124	175	164
532									—	12	89	28	50
554										—	78	16	38
633											—	61	40
641												—	22
642													—

TABLE 23 (CONT.)

EL PASO

	30	37	54	71
30	—	32	60	5
37		—	28	37
54			—	65
71				—

OMAHA

	23	45	51	76	84
23	—	36	57	99	151
45		—	22	63	116
51			—	41	94
76				—	53
84					—

TOLEDO

	103	105	127	146	150	232
103	—	51	81	20	34	160
105		—	138	71	22	144
127			—	61	115	101
146				—	54	140
150					—	166
232						—

TABLE 23 (CONT.)

NEW ORLEANS

	10	14	22	32	41	50	52	62	64	72	75	77	79	80
10	—	81	173	20	61	31	20	159	119	99	126	150	132	81
14		—	92	62	142	112	95	120	160	18	45	68	51	180
22			—	154	126	156	168	30	68	73	46	23	41	79
32				—	81	51	39	178	139	100	107	130	113	118
41					—	30	41	97	58	160	173	150	167	38
50						—	11	127	92	130	157	180	163	68
52							—	42	81	119	146	169	152	111
62								—	39	103	76	52	69	60
64									—	142	115	91	71	21
72										—	27	50	33	162
75											—	28	6	135
77												—	17	112
79													—	129
80														—

TABLE 23 (CONT.)

TUCSON

	5	13	23	36
5	—	70	62	41
13		—	171	112
23			—	77
36				—

NASHVILLE

	535	541	644	715	861
535	—	58	99	110	115
541		—	155	167	59
644			—	12	142
715				—	135
861					—

SAN ANTONIO

	11	16	33	44	53	61	67	71	73
11	—	34	120	149	109	113	118	24	34
16		—	87	178	142	102	96	62	68
33			—	91	131	172	178	145	155
44				—	40	91	81	124	114
53					—	41	47	84	74
61						—	6	43	34
67							—	38	28
71								—	10
73									—

TABLE 23 (CONT.)

SPRINGFIELD

	120	206
120	—	165
206		—

TULSA

	340	421 & 422	503	623 & 624
340	—	51	129	152
421 & 422		—	78	101
503			—	24
623 & 624				—

Zonal Vehicle Trips

For the 75 study zones a model was evolved for the total number of vehicle trips per day attracted and generated by a zone. Total trips consisted of internal trips, external trips, and intrazonal trips. In addition to the previously discussed data, 37 interactions resulted in a total of 68 variables. Tests were made on 70 subsets and the following model was evolved.

$$Y = -7655 - 1326.4\,X_1 + 5.0602\,X_2 - 0.01714\,X_3 + 43.416\,X_4 + 7.2513\,X_5 + 2.07(10^{-6})\,X_6 \qquad \text{(VI)}$$

where:

Y = total number of vehicle trips per day attracted and generated by a zone.

X_1 = straight line distance in miles from the centroid of the central business district to the centroid of the study zone.

X_2 = number of passenger cars owned in the study zone.

X_3 = population of the entire transportation study area.

X_4 = transportation study area in square miles.

X_5 = transportation study density in persons per square mile.

X_6 = three factor interaction of percent of population that are workers in the study zone by the number of people that are in the study zone by the number of cars that are in the study zone.

The amount of variability (R^2) explained by this model is 91.0 percent and the analysis of variance is shown in Table 24. The simple correlation coefficients between the important independent variables studied and the dependent variable of zonal vehicular trips are shown in Table 25.

TABLE 24

ANALYSIS OF VARIANCE FOR ZONAL VEHICULAR TRIPS

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	6	337.967×10^8	56.328×10^8	114.1
Deviations About Regression	68	33.559×10^8	$.494 \times 10^8$	
Total	74	371.526×10^8		

TABLE 25

SIMPLE CORRELATION COEFFICIENTS FOR ZONAL VEHICULAR TRIPS

$r_{y \cdot x}$	Independent Variable
0.909	X_b = population of study zone
-.155	X_c = straight line distance from central business district (X_1)
.204	X_d = area of zone
.450	X_e = population density of zone
.052	X_f = percent white population
-.110	X_g = population per household
-.035	X_h = percent enrolled in school
.122	X_i = family income less than $6000 - percent
-.057	X_j = family income between $6000 - $10,000 - percent
-.027	X_k = family income greater than $10,000 - percent
-.123	X_l = family median income
.137	X_m = percent workers
-.165	X_n = percent using a car to work
.163	X_o = percent employed in standard metropolitan statistical area
-.194	X_p = percent employed in manufacturing
.093	X_q = percent employed in wholesale trade
.206	X_r = percent employed in retail trade
.177	X_s = median value of house
.898	X_t = number of passenger cars (X_2)
.111	X_u = persons per car
.422	X_v = transportation study population (X_3)
.279	X_w = transportation study area (X_4)

TABLE 25 (cont.)

$r_{y \cdot x}$	Independent Variable
0.204	X_x = transportation study population density (X_5)
-.271	X_y = percent units with one automobile in statistical area
.286	X_z = percent using public transportation to work in statistical area
.916	X_bX_m = number of workers
.883	X_bX_h = number enrolled in school
.905	X_bX_y = two factor interaction
.839	X_bX_z = number using public transportation to work
.920	X_bX_o = number that work inside statistical area
.852	X_bX_f = number of white people
.799	X_bX_p = number employed in manufacturing
.885	X_bX_q = number employed in wholesale trade
.920	X_bX_r = number employed in retail trade
.880	$X_bX_mX_t$ = three factor interaction (X_6)

Zone-Central Business District Trips

A model for the number of vehicle trips per day in both directions between each of the 75 study zones and its respective central business district was evolved for the study cities. In addition to the previously tabulated data, 34 interactions resulted in a total of 66 variables. Tests were made on 41 subsets and the following model was evolved.

$$Y = + 498 + 0.46257\ X_1 - 96.700\ X_2 + 0.68270\ X_3 + 0.01331\ X_4 - 0.01967\ X_5 - 0.00300\ X_6 + 0.001767\ X_7 \qquad \text{(VII)}$$

where:

Y = number of vehicle trips per day in both directions between a zone and its central business district.

X_1 = population of the study zone.

X_2 = straight line distance in miles from the centroid of the central business district to the centroid of the study zone.

X_3 = number of passenger cars owned in the study zone.

X_4 = two factor interaction of percent of population that are workers in the study zone by the number of people that are in the study zone.

X_5 = two factor interaction of percent of employed persons who had white collar occupations for the standard metropolitan statistical area by the population of the study zone.

X_6 = three factor interaction of the straight line distance in miles from the centroid of the central business district to the centroid of the study zone by the percent of population that are workers in the study zone by the population of the study zone.

X_7 = three factor interaction of the straight line distance in miles from the centroid of the central business district to the centroid of the study zone by the percent of employed persons who had white collar occupations for the standard metropolitan statistical area by the population of the study zone.

The amount of variability (R^2) explained by this model is 91.7 percent and the analysis of variance is shown in Table 26. The simple correlation coefficients between various independent variables and the dependent variable of zone-central business district trips are shown in Table 27.

Some investigators have related the independent variable of the above model, the number of vehicle trips per day between a zone and the central business district, to the total number of vehicle trips per day attracted and generated by the zone. This relationship for the 75 zones used in this research is shown in Figure 9. The R^2 for this relationship for the study zones was 75.4 percent while that for the evolved model was 91.7 percent.

Interzonal Vehicle Trips

A model for the number of vehicle trips per day in both directions for the zonal interchanges between the non-CBD zones in the study cities was evolved. For this evolution, 48 variables and 100 interactions between those variables were used. After 150 subsets were tried and tested, the following model was evolved.

$$\begin{aligned} Y = {} & 796.2 - 0.1084\ X_1 - 0.04275\ X_2 - 133.7\ X_3 - 6.223\ X_4 \\ & + 15.29(10^{-4})\ X_5 + 20.84(10^{-4})\ X_6 - 0.7401(10^{-2})\ X_7 \\ & + 0.1018(10^{-4})\ X_8 - 0.5256(10^{-5})\ X_9 + 0.7234(10^{-3})\ X_{10} \\ & + 52.37(10^{-6})\ X_{11} + 1.262\ X_{12} - 11.10(10^{-10})\ X_{13} - 3.564(10^{-14})\ X_{14} \\ & - 8.876(10^{-10})\ X_{15} - 0.3867(10^{-11})\ X_{16} + 0.1507(10^{-6})\ X_{17} \\ & - 0.1886(10^{-6})\ X_{18} + 1.443\ X_{19} - 0.1514\ X_{20} - 232.1\ X_{21} \qquad \text{(VIII)} \end{aligned}$$

TABLE 26

ANALYSIS OF VARIANCE FOR ZONE-CENTRAL BUSINESS DISTRICT TRIPS

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	7	177.849×10^6	25.407×10^6	105.9
Deviations About Regression	67	16.073×10^6	$.240 \times 10^6$	
Total	74	193.922×10^6		

TABLE 27

SIMPLE CORRELATION COEFFICIENTS FOR ZONE-CENTRAL BUSINESS DISTRICT TRIPS

$r_{y \cdot x}$	Independent Variable
0.795	X_b = population of study zone (X_1)
-.381	X_c = straight line distance from central business district (X_2)
-.022	X_d = area of zone
.564	X_e = population density of zone
.006	X_f = percent white population
-.323	X_g = population per household
-.218	X_h = percent enrolled in school
.170	X_i = family income less than \$6000 - percent
-.225	X_j = family income between \$6000 - \$10,000 - percent
.030	X_k = family income greater than \$10,000 - percent
-.121	X_l = family median income
.294	X_m = percent workers
-.167	X_n = percent using a car to work
.326	X_o = percent employed in standard metropolitan statistical area
-.236	X_p = percent employed in manufacturing
.164	X_q = percent employed in wholesale trade
.303	X_r = percent employed in retail trade
.145	X_s = median value of house (X_3)
.763	X_t = number of passenger cars
.110	X_u = persons per car
.226	X_v = transportation study population
.107	X_w = transportation study area

TABLE 27 (cont.)

$r_{y\cdot x}$	Independent Variables
.154	X_x = transportation study population density
-.138	X_y = percent units with one automobile in statistical area
.129	X_z = percent using public transportation to work in statistical area
.191	X_{aa} = area of central business district
.077	X_{bb} = percent employed in white collar occupations in statistical area
-.101	X_{cc} = family median income of standard metropolitan statistical area
.841	X_bX_m = number of workers (X_4)
.715	X_bX_h = number enrolled in school
.798	X_bX_y = two factor interaction
.723	X_bX_z = number using public transportation to work
.844	X_bX_o = number that work inside statistical area
.838	X_bX_f = number of white people
.841	X_bX_p = number employed in manufacturing
.949	X_bX_q = number employed in wholesale trade
.956	X_bX_r = number employed in retail trade
.791	X_bX_{bb} = number employed in white collar occupations (X_5)
.445	$X_bX_mX_c$ = three factor interaction (X_6)
.364	$X_bX_{bb}X_c$ = three factor interaction (X_7)

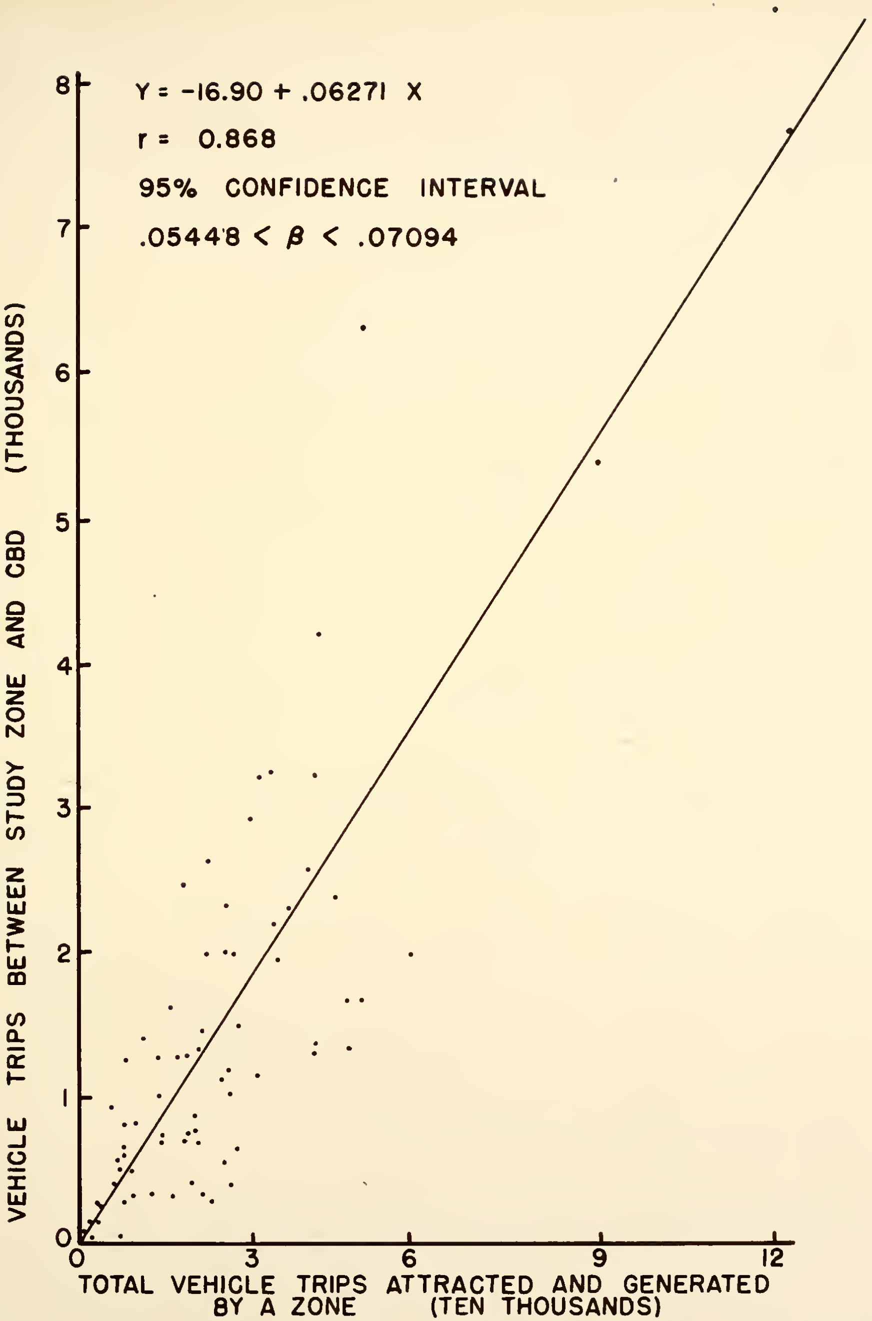


FIG. 9 RELATION BETWEEN CBD TRIPS AND TOTAL TRIPS FOR STUDY ZONES

where:

Y = number of vehicle trips per day in both directions for zonal interchanges between non-CBD zones.

X_1 = number of cars owned in the smaller populated zone.

X_2 = number of cars owned in the larger populated zone.

X_3 = distance in miles between the centroids of the two zones.

X_4 = angle in degrees between centroid of zone i and centroid of zone j with the vertex at the centroid of the central business district.

X_5 = two factor interaction of the population of the smaller populated zone by the percent of population under 34 years that are enrolled in school for that zone. This is a measure of the school enrollment for that zone.

X_6 = two factor interaction of the population of the smaller populated zone by the percent of workers in that zone. This is a measure of the number of workers in that zone.

X_7 = two factor interaction of the population of the smaller populated zone by the straight line distance in miles between the centroids of the two zones.

X_8 = two factor interaction of the population of the larger populated zone by the percent of population under 34 years that are enrolled in school for that zone. This is a measure of the school enrollment for that zone.

X_9 = two factor interaction of the population of the larger populated zone by the percent of workers in that zone. This is a measure of the number of workers in that zone.

X_{10} = two factor interaction of the population of the larger populated zone by the straight line distance in miles between the centroids of the two zones.

X_{11} = two factor interaction of the number of passenger cars owned in one zone by the number of passenger cars owned in the other zone.

X_{12} = two factor interaction of the distance in miles between the centroids of the two zones by the angle in degrees between the two zones with the vertex at the central business district.

X_{13} = four factor interaction of population of a zone by percent of population under 34 years that are enrolled in school in that zone by population of the other zone percent of population under 34 years that are enrolled in school of the other zone. This is a measure of the two factor interaction of school enrollment by school enrollment.

X_{14} = four factor interaction of population of a zone by median income of families in that zone by population of the other zone by median income of families in the other zone.

X_{15} = four factor interaction of population of a zone by percent of workers in that zone by population of the other zone by percent of workers in the other zone. This is a measure of the two factor interaction of workers by workers.

X_{16} = three factor interaction of population of a zone by population of the other zone by transportation study population.

X_{17} = three factor interaction of population of a zone by population of the other zone by percent using public transportation to work for the standard metropolitan statistical area.

X_{18} = three factor interaction of population of a zone by population of the other zone by the straight line distance in miles between the centroids of the two zones.

X_{19} = three factor interaction of the straight line distances in miles between the zone and the central business district, between the other zone and the central business district and between the two zones.

X_{20} = three factor interaction of the straight line distance in miles from the centroid of the zone to the central business district by the distance from the other zone to the central business district by the angle in degrees between the two zones with the vertex at the central business district.

X_{21} = two factor interaction of the population of the smaller zone by the percent of workers in that zone divided by the two factor interaction of the population of the larger zone by the percent of workers in that zone. This is a measure of the ratio of workers between two zones.

The amount of variability (R^2) explained by this model is 70.0 percent and the analysis of variance is shown in Table 28. The simple correlation coefficients between various independent variables and the dependent variable of interzonal vehicle trips are shown in Table 29.

TABLE 28

ANALYSIS OF VARIANCE FOR INTERZONAL VEHICLE TRIPS

Source of Variation	D.F.	Sum of Squares	Mean Squares	F Value
Due to Regression	21	4835×10^4	230×10^4	27.5
Deviation About Regression	247	2071×10^4	8.39×10^4	
Total	268	6906×10^4		

TABLE 29

SIMPLE CORRELATION COEFFICIENTS FOR INTERZONAL VEHICLE TRIPS

$r_{y \cdot x}$		
Smaller Populated Zone	Larger Populated Zone	Independent Variable
0.533	0.282	X_b = population of study zone
-.141	-.126	X_c = straight line distance from central business district
.000	.012	X_d = area of zone
.204	.172	X_e = population density of zone
.135	-.043	X_f = percent white population
-.010	-.150	X_g = population per household
.069	-.127	X_h = percent enrolled in school
.043	.085	X_i = family income less than $6000 - percent
.083	-.053	X_j = family income between $6000 - $10,000 - percent
.046	-.076	X_k = family income greater than $10,000 - percent
.090	-.097	X_l = family median income
.157	.118	X_m = percent workers
.066	-.082	X_n = percent using a car to work
.166	.114	X_o = percent employed in standard metropolitan statistical area
-.015	-.117	X_p = percent employed in manufacturing
.109	.075	X_q = percent employed in wholesale trade
.212	.156	X_r = percent employed in retail trade
.119	-.003	X_s = median value of house
.480 (X_1)	.325 (X_2)	X_t = number of passenger cars

TABLE 29 (Cont.)

$r_{y \cdot x}$		
Smaller Populated Zone	Larger Populated Zone	Independent Variable
.039	.030	X_u = persons per car
.539 (X_6)	.299 (X_9)	$X_b X_m$ = number of workers
.490 (X_5)	.265 (X_8)	$X_b X_h$ = number enrolled in school
.114 (X_7)	.007 (X_{10})	$X_b X_{aa}$ = two factor interaction
0.124		X_v = transportation study population
.136		X_w = transportation study area
.006		X_x = transportation study population density
-.014		X_y = percent units with one automobile in statistical area
.051		X_z = percent using public transportation to work in statistical area
-.396		X_{aa} = straight line distance between zones (X_3)
-.319		X_{bb} = angle between zones (X_4)
.561		$X_{t_i} X_{t_j}$ = two factor interaction (X_{11})
-.341		$X_{aa} X_{bb}$ = two factor interaction (X_{12})
.514		$X_{b_i} X_{h_i} X_{b_j} X_{h_j}$ = four factor interaction (X_{13})
.512		$X_{b_i} X_{1_i} X_{b_j} X_{1_j}$ = four factor interaction (X_{14})
.571		$X_{b_i} X_{m_i} X_{b_j} X_{m_j}$ = four factor interaction (X_{15})
.538		$X_{b_i} X_{b_j} X_v$ = three factor interaction (X_{16})
.521		$X_{b_i} X_{b_j} X_z$ = three factor interaction (X_{17})
.333		$X_{b_i} X_{b_j} X_{aa}$ = three factor interaction (X_{18})

TABLE 29 (Cont.)

$r_{y\cdot x}$		
Smaller Populated Zone	Larger Populated Zone	Independent Variable
	-.235	$X_{c_i}X_{c_j}X_{aa}$ = three factor interaction (X_{19})
	-.274	$X_{c_i}X_{c_j}X_{bb}$ = three factor interaction (X_{20})
	.076	$X_{b_i}X_{m_i} / X_{b_j}X_{m_j}$ = ratio of workers (X_{21})

Summary

Using the eight models developed in this chapter, the current travel pattern of a city within a standard metropolitan statistical area could be developed from data readily obtainable. Such development will require delimiting of the basic areas - transportation study area, central business district, and internal zones. The actual size of each of these basic areas, to utilize the models developed, should be within the ranges shown in Table 30 to avoid increased chance for error through extrapolation. It is also suggested that the boundaries of these areas conform, as much as possible, to the latest census tracts of the community.

TABLE 30

RANGES FOR BASIC AREAS

Area	Range (mi^2)
Transportation Study Area	58.5 - 610.3
Central Business District	0.120 - 0.725
Internal Zones	0.19 - 8.22

To utilize the various models the data listed in Table 31 must be obtained for the current year for the pertinent community.

To estimate the travel pattern for a future time, such as the design year for a freeway, the data stated in Tables 30 and 31 must be estimated for the design year. This is often 20 years after the date of expected construction. Census data will provide information on past trends for

TABLE 31

RANGES OF DATA FOR TRIP PREDICTION

Data	Range
Transportation study population	73260 - 855551
Standard metropolitan statistical area population	117348 - 929383
Transportation study population density (persons per square mile)	397 - 3442
Percent of occupied housing units with one automobile (SMSA Item 71)	49.5 - 62.2
Percent of employed persons using public transportation to work (SMSA Item 49)	2.6 - 30.1
Percent of employed white collar workers (SMSA Item 47)	38.3 - 52.5
Median income of families (SMSA Item 22)	$4766 - 6687
Number of cars owned in each internal zone	0 - 11678
Straight line distance in miles from the centroid of each internal zone to the CBD	0.57 - 9.27
Population of each internal zone	0 - 69666
Percent of population in each internal zone that are workers	0 - 55.19
Angle in degrees between the centroids of zone i and zone j with the vertex at the CBD centroid	5 - 180
Straight line distance in miles between centroid of zone i to centroid of zone j	0.78 - 12.75
Median income of families for each zone	$0 - 19615
Percent of population under 34 years old that are enrolled in school for each zone	0 - 54.17

much of the data required and should permit reasonable estimates for the design year and the development of realistic travel patterns for that year.

TRAFFIC ASSIGNMENT

In order to utilize travel pattern information in freeway **design and** location, a method for estimating the number of these trips that will use the freeway is required. Traffic assignment is the technique normally used for this estimation. It is the determination of the number of trips that will use each of two or more alternate arterial facilities between two zones.

The American Association of State Highway Officials makes the following recommendations (13). "The determination of what traffic would be attracted to a new highway and what would continue to use the existing facilities depends on comparative travel distances, travel times, and economy of operation. The choice is further influenced by the length of trip, comfort, safety, aesthetics, and habit. On the basis of a number of studies on traffic diversion, a practical and sufficiently reliable method of assigning traffic to specific routes has been developed (14). The method recommended is on the basis of travel time, that is, the ratio of travel time via the improved route to the travel time via the quickest alternate route on the existing facilities between given points of origin and destination." The reliable method referred to above resulted in the AASHO Freeway Curve shown in Figure 10 (13).

The only facility with full control of access that was included in the research which resulted in the AASHO Freeway Curve is the Henry G. Shirley Memorial Highway in Virginia and the District of Columbia. The

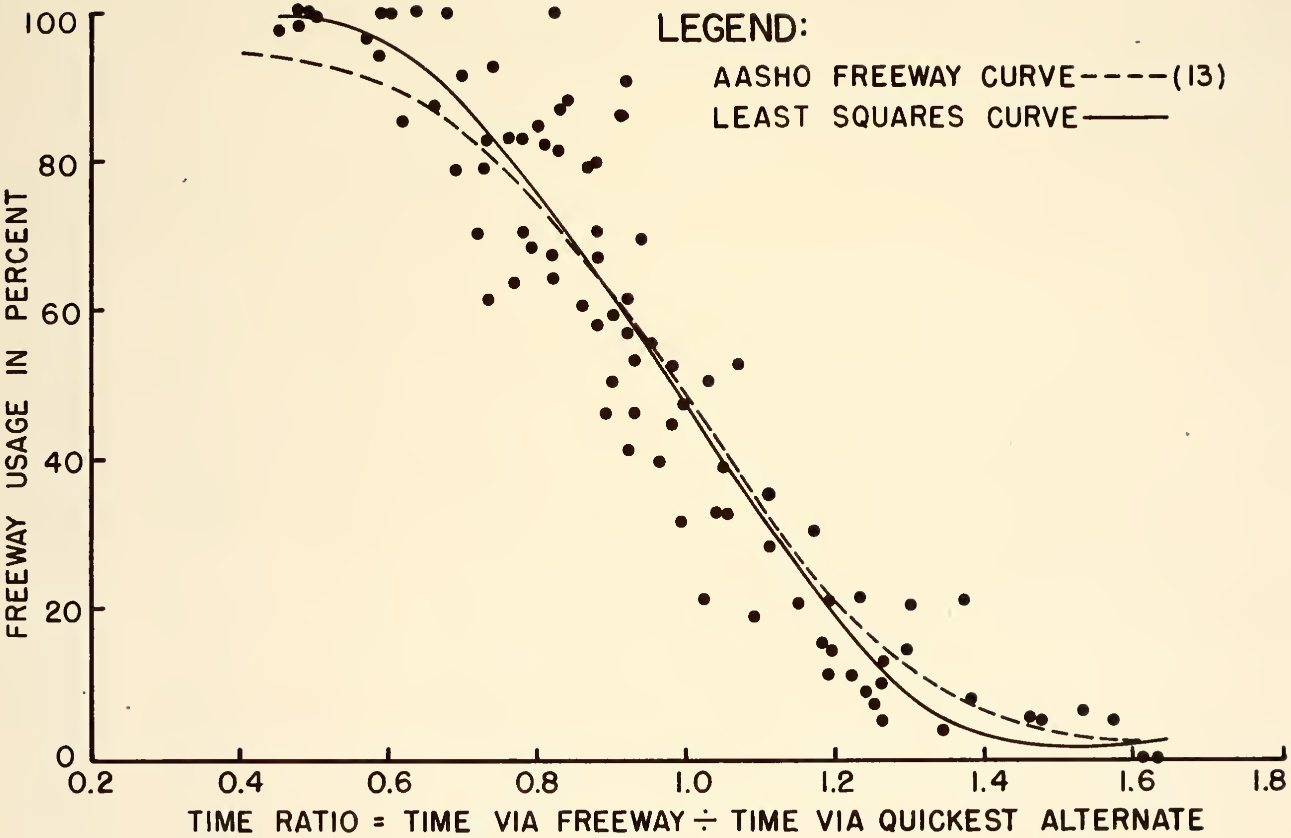


FIG. 10 TRAFFIC DIVERSION CURVE USING TIME RATIO

authors also reported that in order to reduce the number of points for curve fitting the data were summarized by combining it into increments and that all curves were fitted by inspection to the means of these increments. Other measures besides time ratio that have been considered in other studies for the determination of diversion curves are distance ratio, time differential, distance differential, cost ratio, and speed ratio.

Since one of the principal features of freeways is full control of access a more sophisticated analysis was made as a part of the study reported herein on the original data collected from the Shirley Highway. In this analysis several measures - time ratio, distance ratio, time differential, distance differential, and a **combination** of all four measures - were investigated. The analysis included evolving a multiple regression equation, which utilized the testing of hypotheses concerning the regression coefficients at the .05 significance level, and the plotting of curves for freeway usage.

The resulting relation between freeway usage and time ratio is shown in Figure **10** as the solid curve and in the following equation, which explains 89.9 percent of the variation (R^2).

$$Y = 0.116 + 4.148\, X_1 - 5.769\, X_1^{2} + 1.971\, X_1^{3}$$

where:

Y = ratio of number of trips between two origin and destination zones using the Shirley Highway and the total number of trips between the same two zones. This is defined as freeway usage.

X_1 = time ratio, that is, travel time in minutes between the two zones via Shirley Highway divided by the travel time in minutes between the two zones via the quickest alternate. The limits are $0.45 < X < 1.63$.

The relation found between freeway usage and distance ratio is shown in Figure 11 and in the following model. The curve is a straight line with the amount of variability explained by the equation being 60.5 percent.

$$Y = 1.652 - 0.994\, X_2$$

where:

Y = freeway usage.

X_2 = distance ratio, that is, the travel distance in miles between the two zones via Shirley Highway divided by the travel distance in miles between the two zones via the quickest alternalte. The limits are $0.66 < X < 1.93$.

The relation developed between freeway usage and time differential is shown in Figure 12 and in the following equation, which explains 88.9 percent of the variation (R^2).

$$Y = 0.443 + 0.116\, X_3 - 0.00080\, X_3^3$$

where:

Y = freeway usage.

X_3 = time differential, that is, the travel time in minutes between two zones via the quickest alternate minus the travel time in minutes between the two zones via Shirley Highway. The limits are $-6.7 < X < 8.6$ minutes.

The relation evolved between freeway usage and distance differential is shown in Figure 13. The curve is a straight line with the amount of variability explained being 52.4 percent. Its equation is:

$$Y = 0.644 + 0.225\, X_4$$

where:

Y = freeway usage.

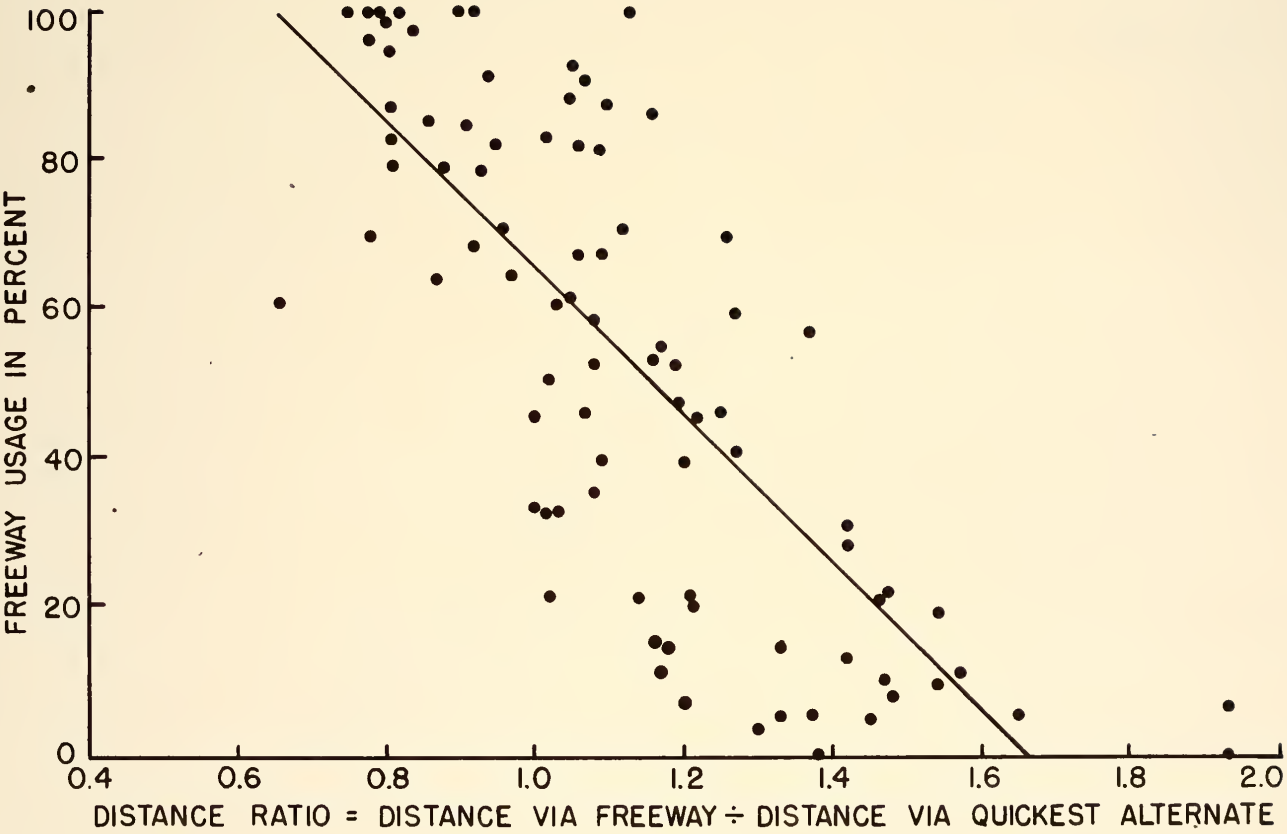


FIG. 11 TRAFFIC DIVERSION CURVE USING DISTANCE RATIO

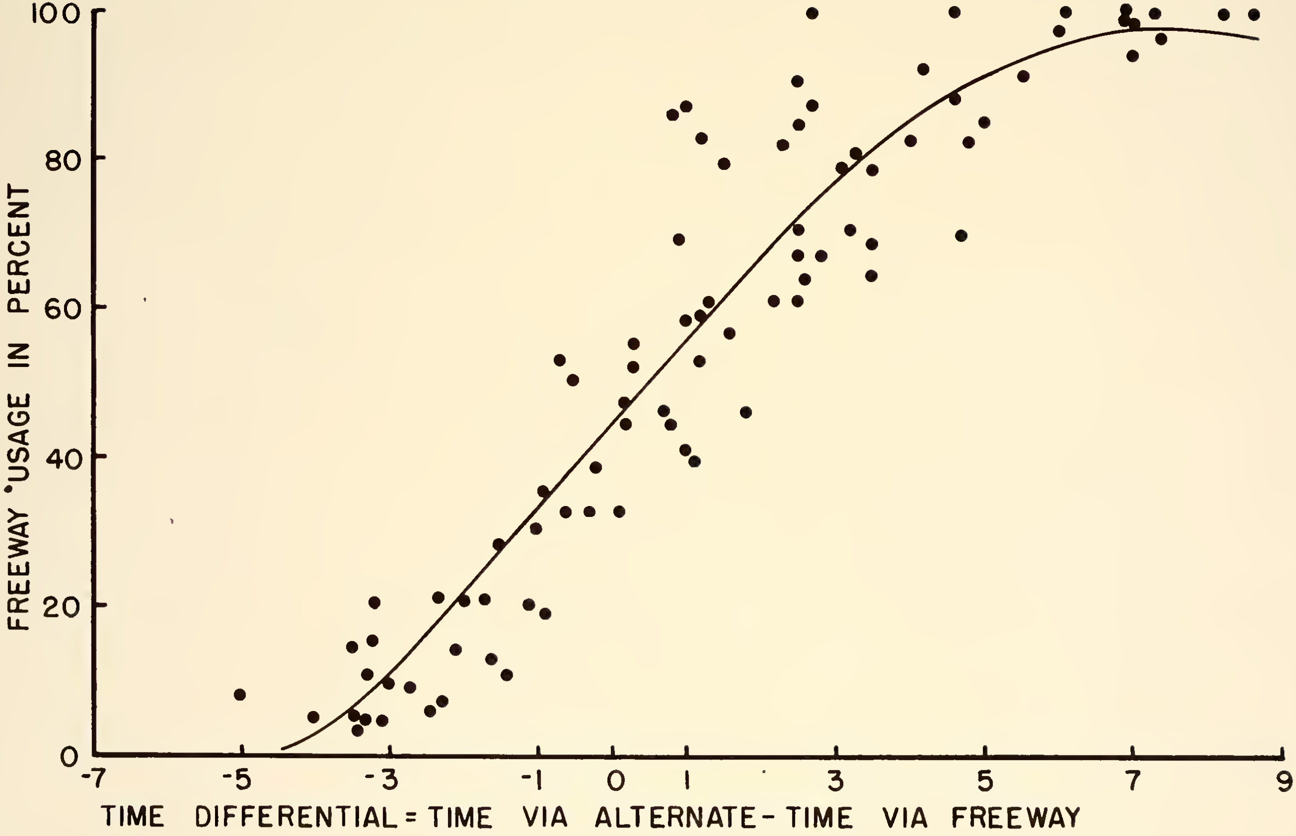


FIG. 12 TRAFFIC DIVERSION CURVE USING TIME DIFFERENTIAL

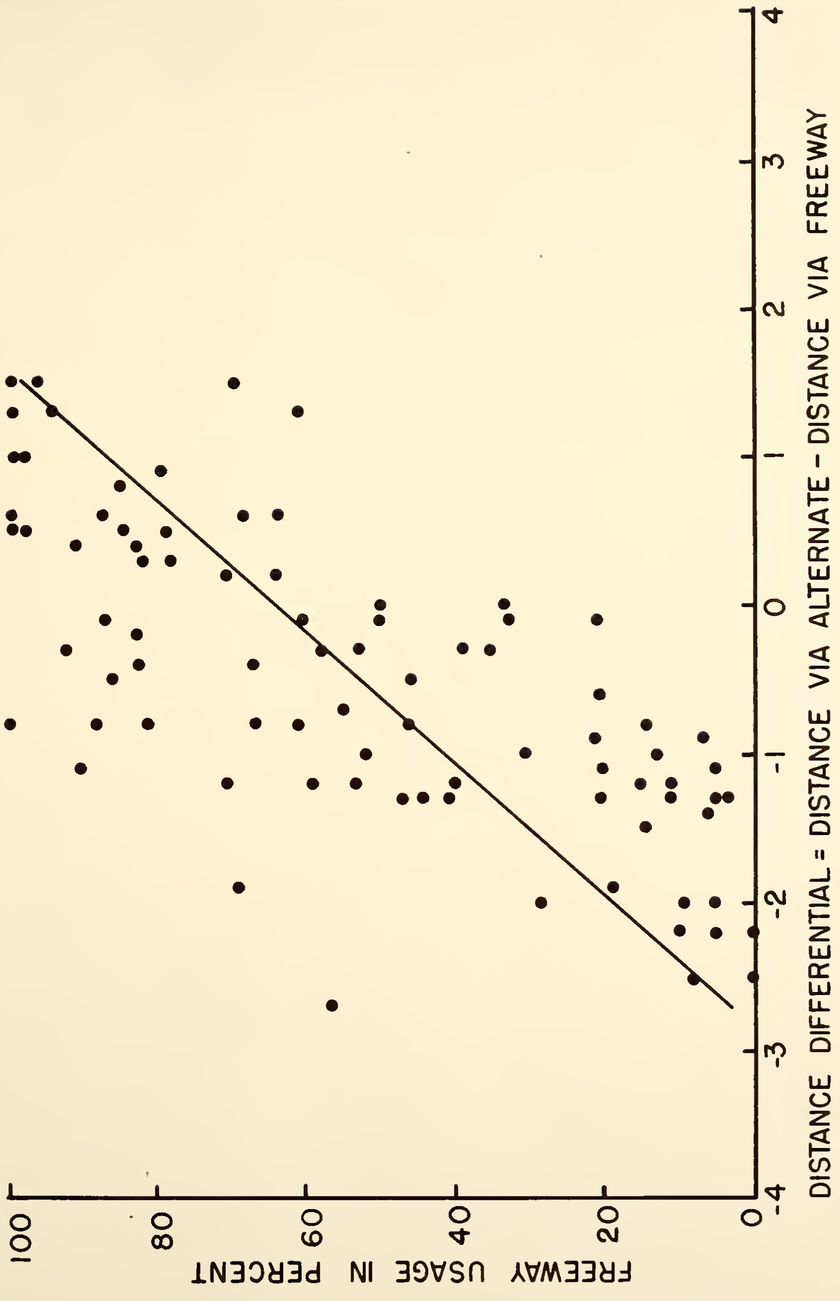


FIG. 13 TRAFFIC DIVERSION CURVE USING DISTANCE DIFFERENTIAL

X_4 = distance differential, that is, the travel distance in miles between two zones via the quickest alternate minus the travel distance in miles between the two zones via Shirley Highway. The limits are $-2.7 < X < 1.5$ miles.

By combining all of the terms in the four equations above into one equation a model that explains 91.2 percent of the variation (R^2) in freeway usage resulted. This equation has different regression coefficients than when the measures were considered separately because of the non-orthogonal data.

$$Y = 0.097 + 3.33 X_1 - 4.29 X_1^2 + 1.46 X_1^3 - 0.156 X_2 + 0.051 X_3 - 0.002 X_3^3 - 0.040 X_4 \qquad \text{(IX)}$$

Where all terms are as given previously.

A summary of some of the characteristics of each of the diversion curves developed from the Shirley Highway data is shown in Table 32.

TABLE 32

SUMMARY OF DIVERSION CURVES

Variable	R^2	Limits
Time Ratio	0.899	0.45 - 1.63
Distance Ratio	0.605	0.66 - 1.93
Time Differential	0.889	-6.7 -+8.6
Distance Differential	0.524	-2.7 -+1.5
All of the Above	0.912	All of the Above

DESIGN HOUR TRAFFIC VOLUME

The assignment of traffic to an arterial facility, such as a freeway, using the models developed in the previous section will result in an estimate of the average daily traffic on the facility. Since the facility should operate efficiently most of the time, the period of greatest interest is that of peak-hour travel. A relationship, therefore, between average daily traffic and peak-hour travel is desired.

The hourly variations in vehicle traffic volumes for sixteen of the daily hours were available for seven of the fourteen study cities. All of the locations were quite similar in pattern as is shown in Figure 14. For all cities the evening peak was the highest and it occurred between 4 p.m. and 6 p.m. The mean for this primary peak was 8.8 percent with a range from 8.3 to 9.3 percent. The secondary peak, which occurred between 7 a.m. and 9 a.m. for all locations, had a mean of 7.1 percent and a range from 6.0 to 8.4 percent. The range, mean, and individual percentages for each city are listed in Table 33.

The hourly traffic variation for all large urban areas may be quite similar, as Figure 15, which shows the hourly average of the seven cities given in Table 33 (all of which had less than one million population), does not indicate a significant variation for the Detroit area, which has approximately four million people. The evening peaks are quite similar, even though the peak hour extends over a longer period of time in Detroit, 3 to 6 p.m.

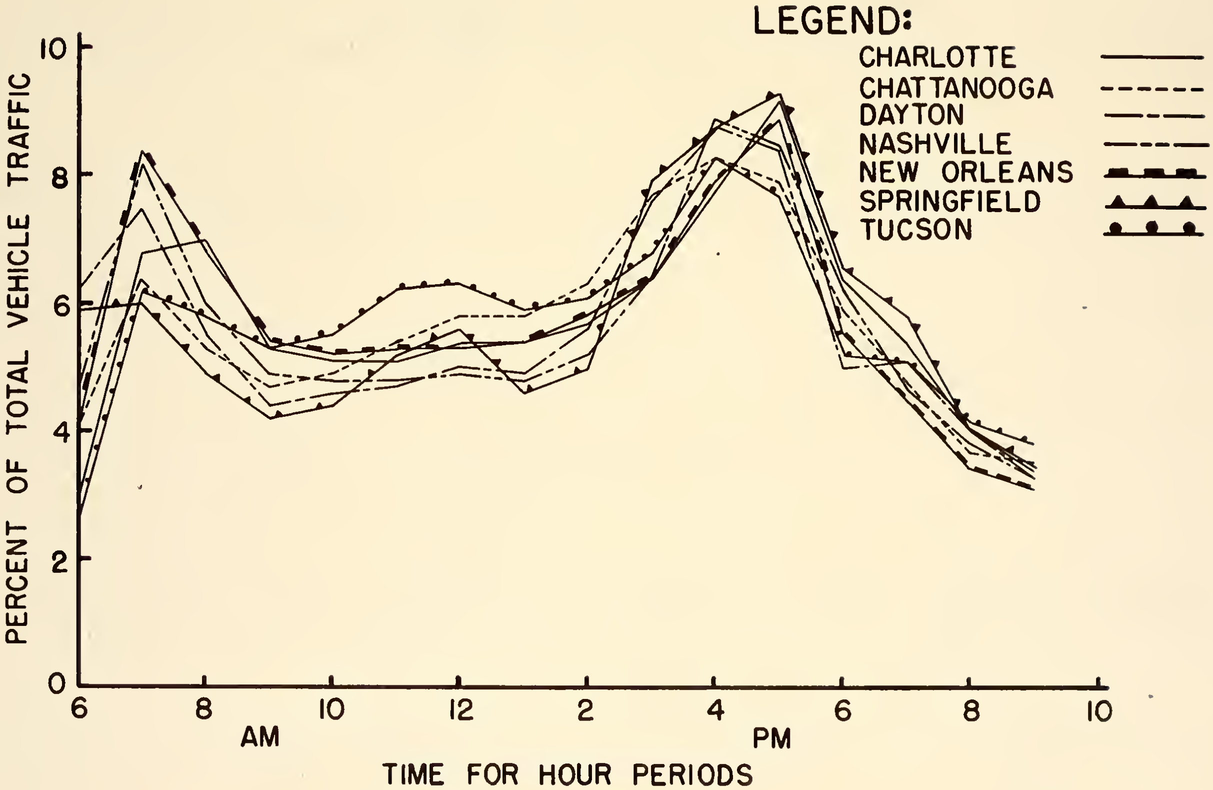


FIG. 14 HOURLY VARIATIONS IN TRAFFIC FLOW FOR 7 CITIES

TABLE 33

HOURLY VARIATIONS IN TRAFFIC VOLUMES

	AM						PM										
	6–7	7–8	8–9	9–10	10–11	11–12	12–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10 PM 6 AM
CHARLOTTE	3.0	6.8	7.0	5.3	5.1	5.1	5.4	5.4	5.7	6.4	7.8	9.2	6.4	5.4	4.0	3.4	8.6
CHATTANOOGA	4.1	6.4	5.3	4.7	4.9	5.4	5.8	5.8	6.3	7.7	8.3	7.9	5.9	4.8	3.7	3.5	9.5
DAYTON	6.2	7.5	5.5	4.4	4.6	4.7	5.0	4.9	5.6	7.6	8.8	8.4	5.0	5.1	4.0	3.3	9.2
NASHVILLE	4.7	8.2	6.0	4.9	4.8	4.8	4.9	4.8	5.2	6.4	8.9	8.5	6.2	4.7	3.8	3.3	9.9
NEW ORLEANS	4.2	8.4	6.8	5.4	5.2	5.3	5.3	5.4	5.8	6.4	7.9	8.9	5.5	4.5	3.4	3.1	8.5
SPRINGFIELD	5.9	6.0	4.9	4.2	4.4	5.2	5.6	4.6	5.0	7.9	8.8	9.3	6.5	5.8	4.0	3.5	8.4
TUCSON	2.7	6.2	5.8	5.3	5.5	6.2	6.3	5.9	6.1	6.8	8.3	7.7	5.2	5.1	4.1	3.8	9.0
RANGE	2.7- 6.3	6.0- 8.4	4.9- 7.0	4.2- 5.4	4.4- 5.5	4.7- 6.7	4.9- 6.3	4.6- 5.9	5.0- 6.3	6.4- 7.9	7.8- 8.9	7.7- 9.3	5.0- 6.5	4.5- 5.8	3.4- 4.1	3.1- 3.8	8.4- 9.9
MEAN	4.4	7.1	5.9	4.9	4.9	5.2	5.4	5.2	5.7	7.0	8.4	8.6	5.8	5.0	3.8	3.4	9.0

AVERAGE OF THE EVENING PEAK HOUR FOR THE SEVEN CITIES = 8.8 PER CENT
RANGE OF THE EVENING PEAK HOUR FOR THE SEVEN CITIES = 8.3 - 9.3 PER CENT
AVERAGE OF THE MORNING PEAK HOUR FOR THE SEVEN CITIES = 7.1 PER CENT
RANGE OF THE MORNING PEAK HOUR FOR THE SEVEN CITIES = 6.0 - 8.4 PER CENT

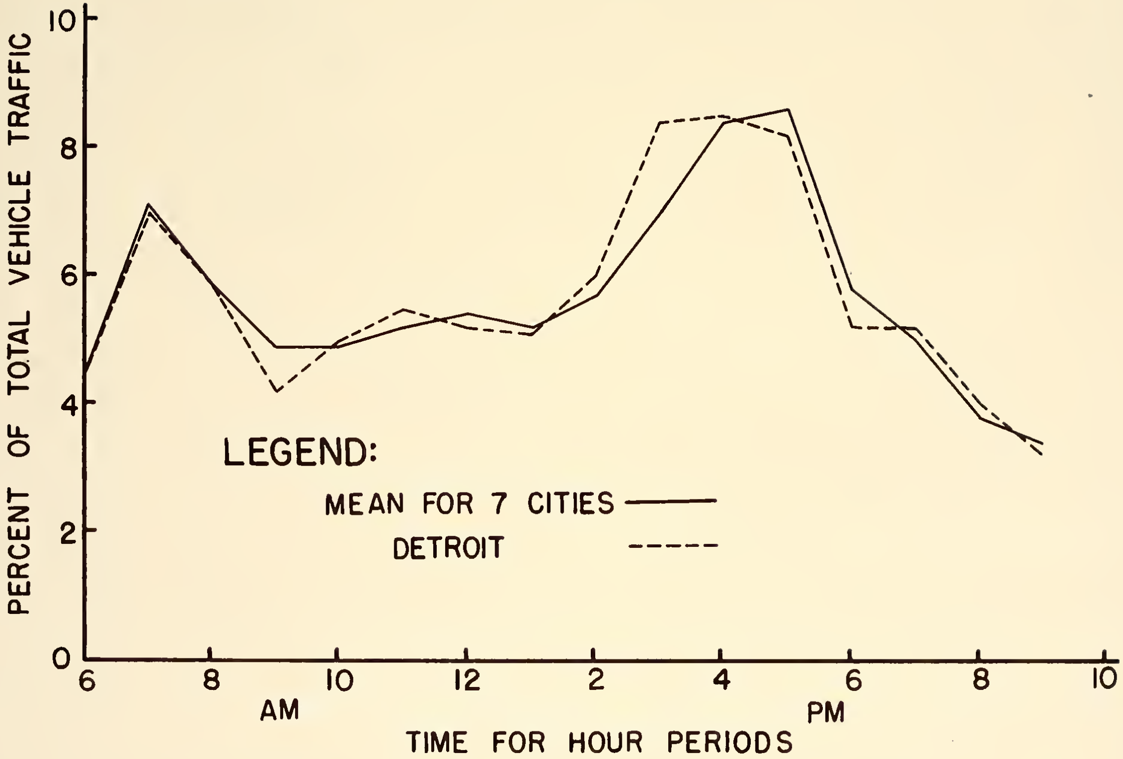


FIG. 15 COMPARISON OF MEAN HOURLY VARIATIONS IN TRAFFIC FLOW WITH DETROIT

Thus it appears that the average peak hour traffic volume for a facility could be estimated quite reliably from the average daily traffic volume of that facility by the use of the mean percentage given in Table 33 for the peak hour.

The average peak hour volume, however, is not normally the one used for design purposes. The peak-hour volume representative of the thirtieth highest hourly volume of the year is the generally accepted criterion. Exception may be necessary in those areas or locations where concentrated recreational or other travel during some seasons of the year results in a distribution of traffic volume of such nature that a sufficient number of hourly volumes are so much greater than the thirtieth highest hourly volume that they cannot be tolerated and a higher value must be considered in design (13).

The typical daily and monthly variations in addition to the hourly variations were available for Chattanooga, Nashville, New Orleans, and Tucson. These two variations are illustrated in Figures 16 and 17. For all four cities the lowest and highest daily variations occurred on Sunday and Friday respectively, but there was a wide range of values. The two Tennessee cities had the lowest monthly variations in February and the highest in June, while Tucson had the highest in February and lowest in July. New Orleans had a peak in January and the lowest percent occurred in March.

Using the hourly, daily, and monthly variations in these four cities, a computer program was written for the estimation of the percent of daily traffic which traveled during 2016 hours of the year in each of the four cities. The equation for this program was

$$C_{ijk} = H_i \times D_j \times M_k$$

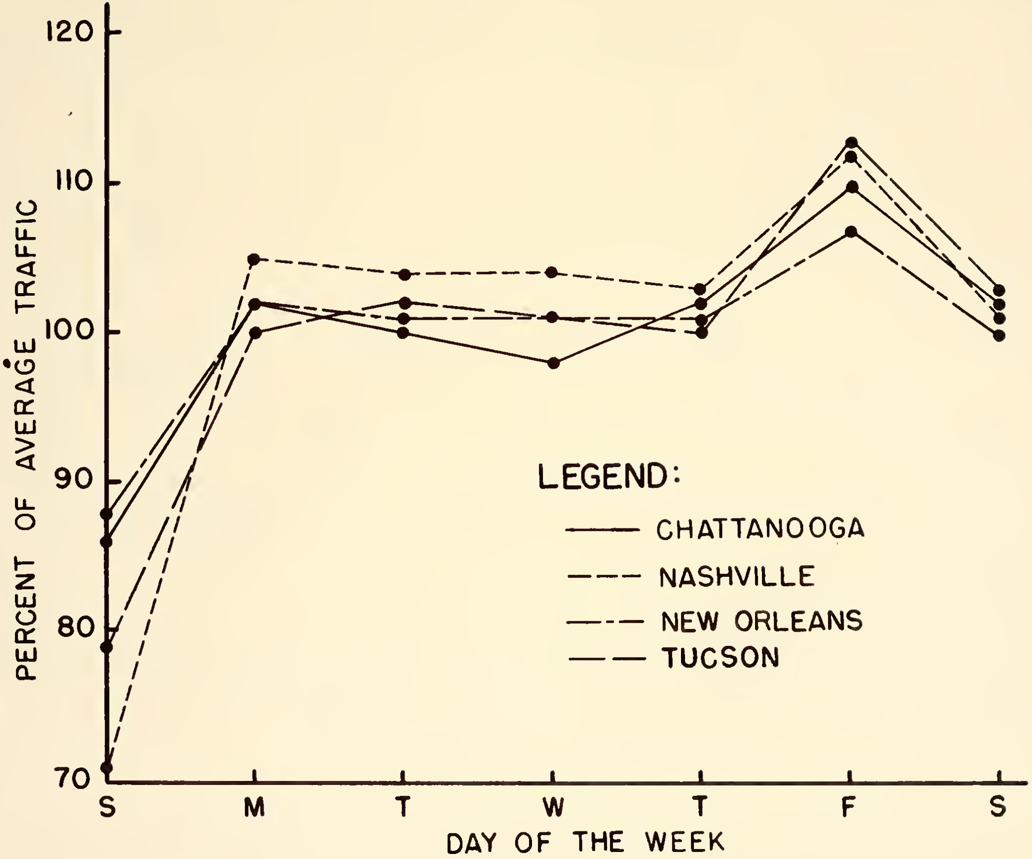


FIG. 16 DAILY VARIATIONS IN TRAFFIC FLOW

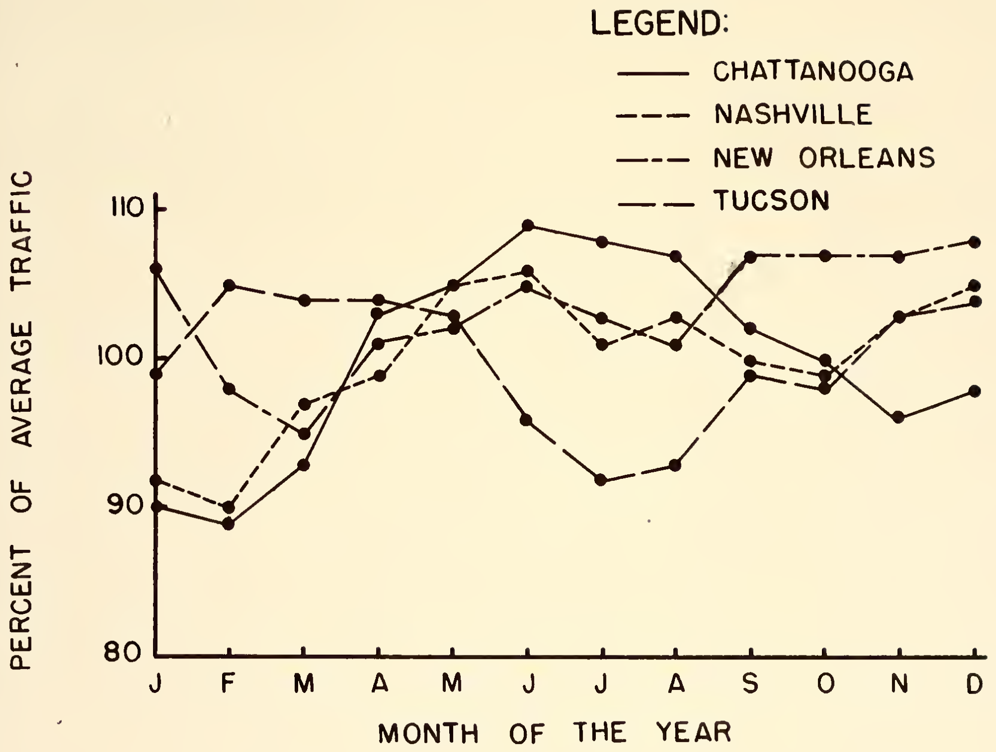


FIG. 17 MONTHLY VARIATIONS IN TRAFFIC FLOW

Where:

C_{ijk} = percent of hourly traffic divided by the annual average daily traffic for the ith hour of the jth day in the kth month.

H_i = percent of hourly traffic for the ith hour,

$i = 1,2, \ldots 24.$

D_j = daily factor for the jth day, obtained by dividing the volume of traffic on the jth day by the average daily volume,

$j = 1,2, \ldots 7.$

M_k = monthly factor for the kth month, obtained by dividing the volume of traffic in the kth month by the average monthly volume,

$k = 1,2, \ldots 12.$

Except for a few special events which might have had unusually high volumes of traffic in these cities, the values obtained from the equation are representative of all hours of the year because the weekly variations in traffic within one month (which were not included) are small and generally not enumerated in a volume count program. The program for the IBM 7090 computer for these calculations is shown in Figure 18.

The analysis made on the data from the four cities is summarized in Table 34, which also shows the average values from the Highway Capacity Manual for 38 locations in eight cities (15). It is interesting to note the small difference in percentages for the highest 100 hours in each of the four cities. Close agreement between their means and the means from the Manual exists with the largest difference occurring at the highest hour. The values from the four cities are also in agreement with the suggested values of the American Association of State Highway Officials, which are 7 to 18 percent of the average daily traffic with a mean of 11 percent.

```
*       XEQ
*       LABEL
        DIMENSION S(12),D(7),H(24),HVF(2016)
        DO 22 I=1,12,1
        READ INPUT TAPE 5,2,S(I)
   22   CONTINUE
        DO 23 I=1,7,1
        READ INPUT TAPE 5,2,D(I)
   23   CONTINUE
        DO 24 I=1,24,1
        READ INPUT TAPE 5,2,H(I)
    2   FORMAT (F6.2)
   24   CONTINUE
    3   IJ=0
    4   DO 10 L=1,12,1
    5   DO 10 M=1,7,1
    6   DO 10 N=1,24,1
    7   IJ= IJ+1
    8   HVF(IJ)=S(L)*D(M)*H(N)
   10   CONTINUE
   11   DO 17 IK=1,2015,1
   12   DO 17 IL=2,2016,1
   13   IF (HVF(IK)-HVF(IL))14,17,17
   14   TEMP=HVF(IK)
   15   HVF(IK)=HVF(IL)
   16   HVF(IL)=TEMP
   17   CONTINUE
   18   WRITE OUTPUT TAPE 6,19,(HVF(L),L=1,2016)
   19   FORMAT (1X,10F11.2)
   20   CALL EXIT
   21   END
*       DATA
```

FIG. 18 PROGRAM FOR CALCULATION AND RANKING OF PERCENT OF HOURLY TRAFFIC

TABLE 34

HOURLY PERCENT OF AVERAGE DAILY TRAFFIC

	Highest	10th	20th	30th	50th	100th	180th	Lowest
Chattanooga	10.0	9.8	9.5	9.4	9.2	9.0	8.7	0.3
Nashville	10.6	10.5	10.3	10.1	9.9	9.7	9.4	0.5
New Orleans	10.1	9.8	9.6	9.5	9.5	9.3	9.1	0.3
Tucson	9.8	9.8	9.7	9.3	9.1	8.9	8.6	0.3
Mean	10.1	10.0	9.8	9.6	9.4	9.2	9.0	0.4
Highway Capacity Manual[1]	12.4	10.9	10.5	10.2	9.5	N.A.[2]	N.A.	N.A.

1 - Average for 38 locations in 8 cities

2 - N.A. - Not Available

Table 34 also verifies the characteristic that the fluctuation in peak-hour volumes from day-to-day in any one year is relatively small on urban arterials (13). From these observations, a value of ten percent of the average daily traffic should be a good estimate for the design hour volume in an urban area within a standard metropolitan statistical area.

This relation between the design hour volume (30th highest hour) and average daily traffic on urban facilities is lower than on rural facilities, as is illustrated in Figure 19, which shows the curves for the mean of the study cities, the average for 167 main rural highway locations in 48 states (16), and an urban through route from the Connecticut State Highway Department (17).

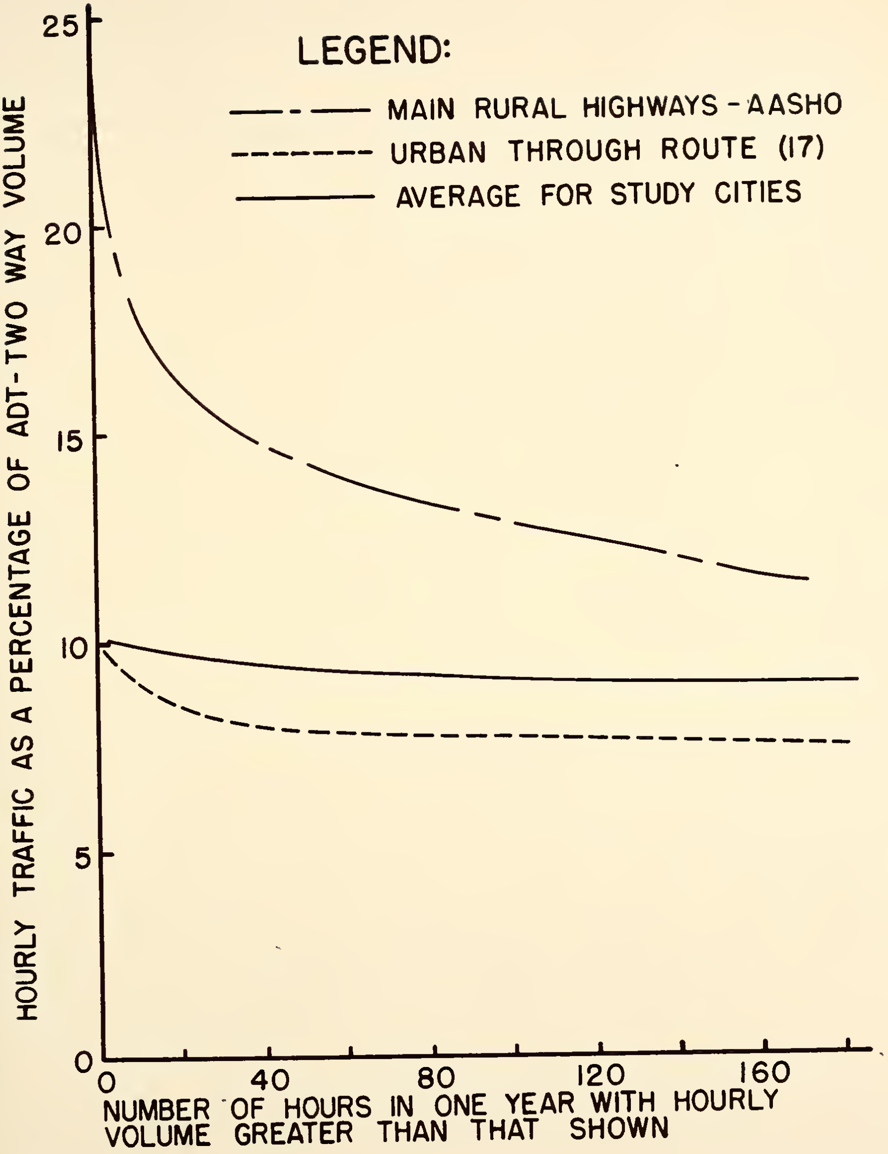


FIG. 19 RELATION BETWEEN PEAK-HOUR AND AVERAGE DAILY TRAFFIC VOLUMES

SOME IMPORTANT VARIATIONS IN DESIGN HOUR VOLUMES

The volume of traffic during the design hour is that volume in the design year for which sufficient capacity should be provided. The capacities required for a freeway and its interchange ramps, however, are vitally affected by the number of trucks in the design hour volume and in the distribution of the direction of travel during the design hour.

Average daily traffic volume consists of passenger cars and trucks. Light delivery trucks, such as panels and pickups are normally considered as passenger cars. Trucks include all buses, single-unit trucks, and truck combinations, that is, vehicles with dual tires on the rear axle or those having 9000 pounds or greater gross vehicle weight rating. Truck trips during the design hour often are considered as a percentage of total vehicular traffic and are referred to by the letter T (13).

Average daily truck trips averaged 16.20 percent of the total vehicular trips for the fourteen study cities and ranged from 7.39 percent in Huntsville to 25.98 percent in New Orleans. A regression analysis relating truck trips to total vehicle trips for all the cities was made and the relation is given below.

$$Y = -19900.5 + 0.20631\,X \qquad \text{(X)}$$

Where:

Y = truck trips per day in the study area

X = total vehicle trips per day in the study area

Table 35 shows the number of truck trips, percent of truck trips and the estimated number of truck trips from the regression equation. The relationship between truck trips and total vehicle trips is shown in Figure 20.

The hourly variations in truck volumes varied considerably from the hourly variations in total vehicular volumes for the four cities for which these variations were available as is evidenced from Table 36 and Figure 21. None of the four cities had the truck peak hours occurring from 4 p.m. to 6 p.m., which were the peak hours for total vehicle trips, but had peaks beginning at 8 a.m., 9 a.m., 10 a.m., and 2 p.m. The mean percent of trucks traveling during the peak hour of total travel (4 - 6 p.m.) was 7.2 percent of total truck trips.

A value for the percent of total vehicle trips that are truck trips at the design hour may be estimated from the equation below.

$$T = \frac{K_T \text{ ADT Trucks}}{K \text{ ADT}} \times 100$$

Where:

T = percent of total vehicles that are trucks at the design hour.

K_T = percent of truck trips at the design hour.

K = percent of total trips at the design hour.

ADT_{Trucks} = average daily traffic of trucks at the design year.

ADT = average daily traffic of vehicles at the design year.

K_T was found to have a mean value of 7.2 for the four cities of this study which had this information available. A good value for K was

TABLE 35

TRUCK TRIP DATA

Location	Truck Trips Internal	Truck Trips External[1]	Truck Trips Total	Per Cent of Total Vehicle Trips	Estimated Total Truck Trips
Charlotte	51918	18729	70647	16.29	69574
Chattanooga	64022	13894	77916	18.56	66702
Dayton	56704	17651	74355	9.99	133583
Denver	216154	13617	229771	16.82	261874
El Paso	73457	9884	83341	19.06	70292
Huntsville	7150	2782	9932	7.39	7839
Nashville	90987	15795	106782	17.79	103919
New Orleans	278953	12653	291606	25.98	211625
Omaha	71994	10846	82840	17.86	75773
San Antonio	169292	17877	187169	21.42	160366
Springfield	17341	8277	25618	12.07	23890
Toledo	N.A.	N.A.	83505	10.90	138155
Tucson	57260	5042	62302	13.62	74487
Tulsa	73426	13828	87254	18.98	74959

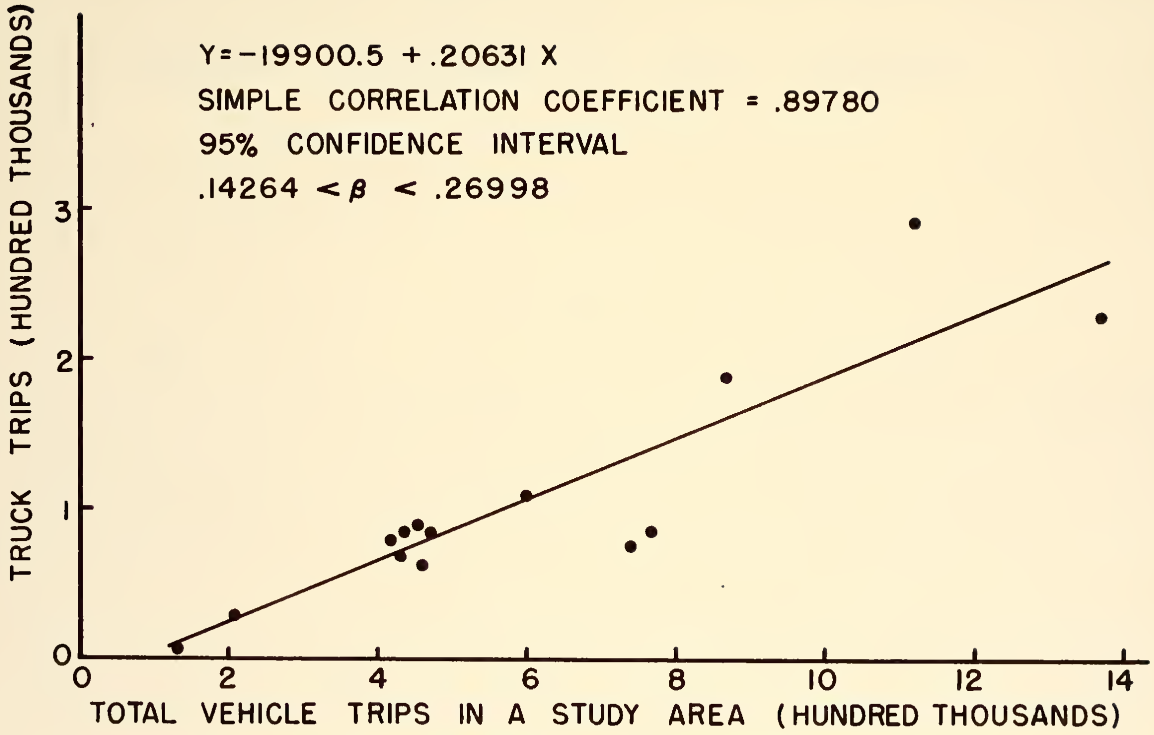


FIG. 20 RELATION BETWEEN TRUCK TRIPS AND TOTAL VEHICLE TRIPS

TABLE 36

HOURLY VARIATIONS IN TRUCK VOLUMES[1]

PERCENT

	AM						PM										
	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10 PM 6 AM
DAYTON	3.4	7.7	8.9	8.4	8.6	7.4	7.5	7.9	8.8	8.2	7.1	5.0	2.6	1.7	1.2	1.0	4.6
EL PASO	2.5	5.9	8.5	8.6	9.5	9.1	7.6	7.8	7.8	7.8	9.0	7.2	3.8	1.5	0.9	0.4	2.1
OMAHA	2.2	3.0	6.3	8.0	8.5	6.8	6.0	6.0	10.2	8.8	9.3	7.0	4.5	2.3	2.7	2.3	6.1
SPRINGFIELD	3.1	5.7	8.0	8.5	7.9	8.0	7.4	7.1	7.1	8.2	7.7	5.5	3.4	1.9	1.6	1.3	7.6
RANGE	2.2-3.4	3.0-7.7	6.3-8.9	8.0-8.6	7.9-9.5	6.8-9.1	6.0-7.6	6.0-7.9	7.1-10.1	7.8-8.8	7.1-9.3	5.0-7.2	2.6-4.5	1.5-2.3	0.9-2.7	0.4-2.3	2.6-7.6
MEAN	2.8	5.6	7.9	8.4	8.6	7.8	7.1	7.4	8.4	8.2	8.3	6.2	3.6	1.8	1.6	1.2	5.1

---

[1] – $\text{VARIATION} = \dfrac{\text{HOURLY TRUCK TRIPS}}{\text{TOTAL TRUCK TRIPS}} \times 100$

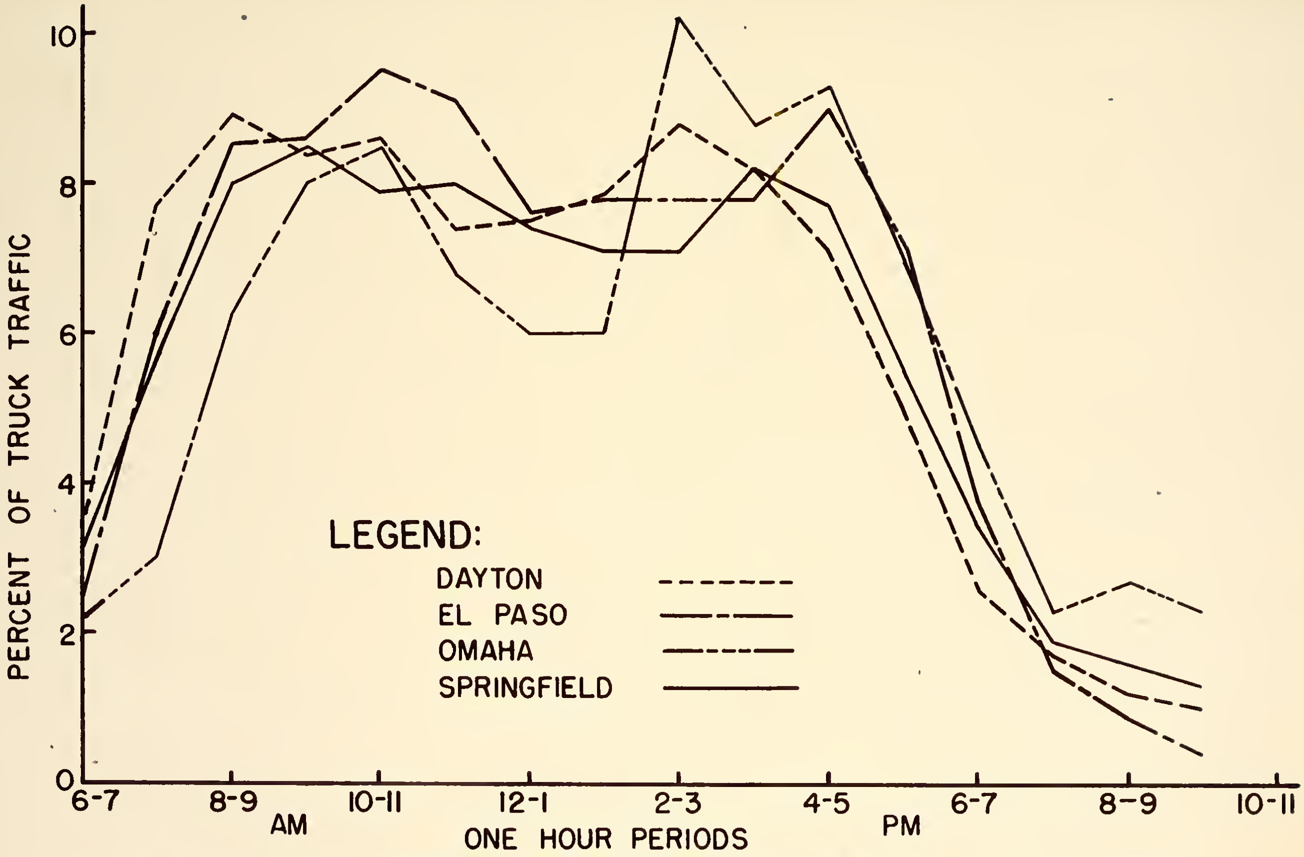


FIG. 21 HOURLY VARIATION IN TRUCK VOLUMES (PERCENT)

previously shown to be 10.0 percent. The use of these values will permit an estimation of T which should be adequate for the determination of capacity requirements during the design hour.

The second factor previously mentioned as important in the determination of capacity requirements was directional distribution of traffic volume during the design hour. Considerable research on this factor has indicated that rarely is traffic evenly distributed during the design hour, although this situation may be approached in and near the central business area (15). The amount of traffic flowing in the direction of heavier movement in urban areas has normally been found to range from 55 percent near the central business district to 60 percent in intermediate areas to 65 percent in outlying areas (15).

AN APPLICATION

The techniques and models developed in the previous sections of this report will permit the development of the travel patterns of urban areas. The models on traffic assignment, peak hour travel, design hour volumes, and truck trips will permit the translation of the travel patterns to daily and hourly vehicular volumes.

The uses of this information are many but a major use of these data will undoubtedly be in the location of design of freeways and their interchanges. As an example of the use of the developed models, the location of the interchanges on a freeway in a hypothetical city will be illustrated.

The location of a freeway interchange has often been determined by the location of existing arterial-streets and requirements of safe and efficient operation of the freeway. The latter requirements have resulted in generally accepted minimum distances between interchanges. Certainly some minimum distance is necessary to obtain safe and efficient operation on the freeway. It is also obvious that the capacities provided at an interchange must be at least equal to the volumes to be served.

Some interchange elements, however, cannot be designed for a capacity below a certain minimum. A freeway ramp for example cannot be efficiently designed for a capacity of less than that of one lane, about 1200 vehicles per hour. Furthermore any interchange is an expensive undertaking and economics dictate that the number of interchanges should be kept to a minimum. These considerations indicate that interchanges should be located

so as to minimize the annual cost of such facilities, including road user costs and highway costs - construction, maintenance, operation, etc. Included in road user costs are time, distance, and other costs to the motorist.

A major factor in annual highway cost is the initial cost of the highway facility. This cost typically decreases for a freeway with a decrease in the number of interchanges. This decrease, however, may be quite small or may be negligible for certain locations, as it is dependent in the types of interchanges required, costs of land, capacities required, and other factors. Annual highway costs, therefore, must be determined for each possible location of an interchange.

Road user costs, on the other hand, generally increase as the number of interchanges decrease. This occurs because travel time is increased for many motorists as they must travel longer distances on other than freeway type facilities. Distance also may increase as may costs of operation.

The optimum number and location of freeway interchanges, therefore, must be based on an economic analysis of the freeway with alternate numbers and locations of its interchanges. Annual highway costs for each alternate can be determined on the basis of the design necessary to provide the needed capacity at each possible location. Road user costs can be determined for the traffic estimated to use the freeway as determined from the travel pattern analysis and traffic assignment procedures previously developed. Because the most efficient utilization of an interchange generally occurs when the design hour volume for one of the ramps is equal to the capacity of the traffic lanes of that ramp in the design year, the minimum annual

cost of a freeway will often occur when the interchanges are located so as to serve such volumes of traffic. And it is these volumes of traffic which can be estimated by using the models developed in this research.

The hypothetical city of this example is shown in Figure 22. A freeway has been located using the travel patterns developed for the city and possible locations of interchanges are shown.

Travel Pattern Development

The development of the travel patterns for this city required the determination of the following:

1. Total vehicle trips in the study area. By the use of Model I previously evolved, an estimate of the total vehicle trips per day, including interzonal, intrazonal, external, and through trips, was computed. This estimate is a measure of the magnitude of the vehicular transportation problem in an area.

2. Ratio of external vehicle trips to total vehicle trips in the study area. The use of Model II provided this information.

3. Ratio of external - internal vehicle trips to internal vehicle trips. Model III gave an estimate of the ratio of daily external - internal vehicle trips, that is, local trips to internal vehicle trips.

4. Vehicle trips to and from the central business district. This previously evolved model (Model IV) gave an estimate of the vehicle trips per day in both directions for the central business district.

5. Intrazonal central business district trips. An estimate of the daily vehicle trips that have both ends within the central business district was computed by the use of Model V. This is an estimate of the trips that might be discouraged from using the freeway because of their short length.

6. Total vehicle trips attracted and generated by a zone. This previously evolved model (Model VI) gave an estimate of the daily vehicle trips generated and attracted by each zone. There were as many estimates as there were study zones, excluding the central business district.

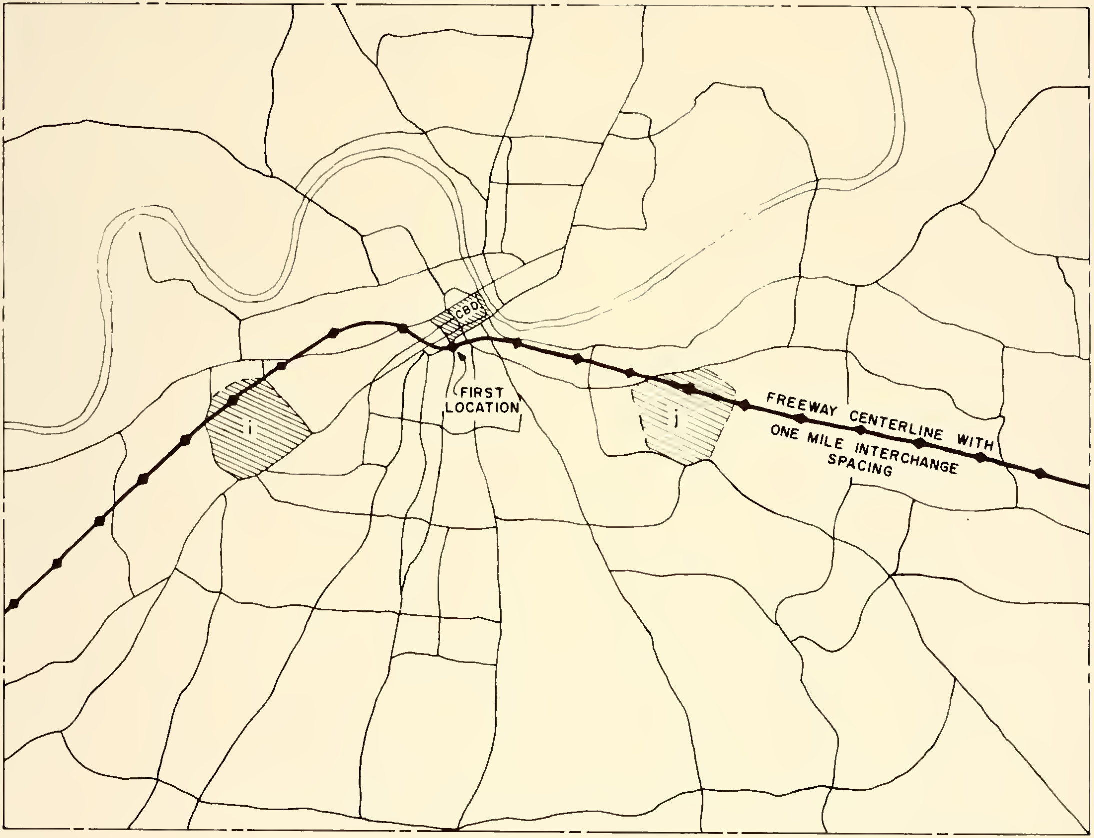


FIG. 22 TYPICAL MAJOR ARTERIAL SYSTEM

7. Zone-central business district trips. The use of Model VII gave an estimate of the daily number of vehicle trips in both directions between each zone and the central business district. There were as many estimates as there were study zones, excluding the central business district.

8. Interzonal vehicle trips. This previously evolved model (Model VIII) gave an estimate of the vehicle trip interchanges per day in both directions between any two zones of the transportation study area. There were 1/2 K (K - 1) estimates for the transportation study area where K was equal to the number of zones excluding the central business district.

9. Truck trips in the study area. This estimate was obtained by using Model X. This information also gives a measure of the importance of this type of vehicle in the entire transportation study area.

To obtain actual values from the nine models listed above certain data from the study city was required. Data used in the example is as follows:

	Transportation study area	250 mi.^{2}
	Central business district area	0.50 mi.^{2}
Area Data	Number of internal zones including CBD	100
	Area of each zone	
	Area of zone i (example only)	2.0 mi.^{2}
	Area of each zone	
	Area of zone j (example only)	2.3 mi.^{2}
	Transportation study population	500,000
	Standard metropolitan statistical area population	600,000
Transportation Study	Transportation study population density	2000 persons/mi.^{2}

	Percent of occupied units with one automobile	56.0 percent
	Percent of employed persons using public transportation to work	10.0 percent
	Percent of employed white collar workers	45.0 percent
	Median income of families	$5700
Zonal Data for Each Zone (Data for two zones given as an example)	Number of cars owned in zone i	2800
	Number of cars owned in zone j	3000
	Straight line distance from centroid of zone i to CBD	4.0 mi.
	Straight line distance from centroid of zone j to CBD	4.1 mi.
	Population of zone i	9500
	Population of zone j	10,500
	Percent of population in zone i that are workers	36.5 percent
	Percent of population in zone j that are workers	34.5 percent
	Median income of families for zone i	$5700
	Median income of families for zone j	$5900
	Percent of population of zone i under 34 years old enrolled in school	28.5 percent
	Percent of population of zone j under 34 years old enrolled in school	26.5 percent
	Angle in degrees between zone i and zone j with vertex at CBD	128°
	Straight line distance in miles between centroids of zone i and zone j	7.25 mi.

All of the data given above can be obtained for a study city from latest census reports, land use maps of the study area, vehicle registration lists for the city, and maps of the city showing the various zones delineated for the study.

Using the values given in the appropriate models resulted in the following sample estimates for the example city:

1. Total daily vehicle trips in the transportation study area - Model I

$$Y = +\ 142010 + 1.53441\ (500{,}000) - 8731.8\ (10.0)$$
$$= 821898 \text{ trips/day}$$

2. Ratio of external vehicle trips per day to total vehicle trips per day for the study area - Model II

$$Y = 0.4126 + 10^{-10}\ \left[0.0242\ (500{,}000)\ (250)^2 - 4644.2\ (500{,}000) - 11351\ (250)^2 + 452.1\ (2000)^2 - 1576380\ (2000)\right]$$
$$= .0506 = 5.06\%$$

3. Ratio of local vehicle trips per day, that is, external - internal movements to the internal vehicle trips per day for the study area - Model III

$$Y = +\ 0.545 + 10^{-7}\ \left[-\ 0.0267\ (500{,}000)\ (250) - 17.4\ (250)^2 + 7.00 \times 10^{-5}\ (500{,}000)\ (250)^2 + 0.656\ (2000)^2 - 2774\ (2000)\right]$$
$$= .029 = 2.9\%$$

4. Vehicle trips per day to and from the central business district - Model IV

$$Y = -\ 39570 + 0.04948\ (500{,}000) + 41335\ (0.50) - 1443.9\ (10.0) + 1492.0\ (45.0) + 28.755\ (0.50)\ (2000)$$
$$= 87294 \text{ trips/day}$$

5. Intrazonal central business district trips per day - Model V

$$\begin{aligned} Y &= + 5790 + 6407\ (0.50) + 0.8432\ (2000) \\ &\quad - 1.185\ (5700) - 0.00017\ (500{,}000)\ (10.0) \\ &\quad + 0.01909\ (500{,}000)\ (0.50) \\ &= 7848 \text{ trips/day} \end{aligned}$$

6. Total number of vehicle trips per day attracted and generated by zone i - Model VI

$$\begin{aligned} Y &= -7655 - 1326.4\ (4.0) + 5.0602\ (2800) \\ &\quad - 0.01714\ (500{,}000) + 43.416\ (250) \\ &\quad + 7.2513\ (2000) + 2.07 \times 10^{-6}\ (36.5)\ (9500)\ (2800) \\ &= 20004 \text{ trips/day} \end{aligned}$$

Total number of vehicle trips per day attracted and generated by zone j - Model VI

$$\begin{aligned} Y &= - 7655 - 1326.4\ (4.1) + 5.0602\ (3000) \\ &\quad - 0.01714\ (500{,}000) + 43.416\ (250) \\ &\quad + 7.2513\ (2000) + 2.07 \times 10^{-6}\ (34.5)\ (10500)\ (3000) \\ &= 21125 \text{ trips/day} \end{aligned}$$

7. Vehicle trips per day in both directions between zone i and CBD - Model VII

$$\begin{aligned} Y &= + 498 + 0.46257\ (9500) - 96.700\ (4.0) \\ &\quad + 0.68270\ (2800) + 0.01331\ (9500)\ (36.5) \\ &\quad - 0.01967\ (9500)\ (45.0) - 0.00300\ (4.0)\ (36.5)\ (9500) \\ &\quad + 0.001767\ (4.0)\ (45.0)\ (9500) \\ &= 1484 \text{ trips/day} \end{aligned}$$

Vehicle trips per day in both directions between zone j and CBD - Model VII

$$
\begin{aligned}
Y = &+ 498 + 0.46257\ (10500) - 96.700\ (4.1) \\
&+ 0.68270\ (3000) + 0.01331\ (10500)\ (34.5) \\
&- 0.01967\ (10500)\ (45.0) - 0.00300\ (4.1)\ (34.5)\ (10500) \\
&+ 0.001767\ (4.1)\ (45.0)\ (10500) \\
= &\ 1501 \text{ trips/day}
\end{aligned}
$$

8. Vehicle trips per day in both directions between zone i and zone j - Model VIII

$$
\begin{aligned}
Y = &\ 796 - 0.1084\ (2800) - 0.04275\ (3000) \\
&- 133.7\ (7.25) - 6.223\ (128) \\
&+ 15.29\ (10^{-4})\ (9500)\ (28.5) \\
&+ 20.84\ (10^{-4})\ (9500)\ (36.5) \\
&- 0.7401\ (10^{-2})\ (9500)\ (7.25) \\
&+ 0.1018\ (10^{-4})\ (10500)\ (26.5) \\
&- 0.5256\ (10^{-5})\ (10500)\ (34.5) \\
&+ 0.7234\ (10^{-3})\ (10500)\ (7.25) \\
&+ 52.37\ (10^{-6})\ (2800)\ (3000) \\
&+ 1.262\ (7.25)\ (128) \\
&- 11.10\ (10^{-10})\ (9500)\ (28.5)\ (10500)\ (26.5) \\
&- 3.564\ (10^{-14})\ (9500)\ (5700)\ (10500)\ (5900) \\
&- 8.876\ (10^{-10})\ (9500)\ (36.5)\ (10500)\ (34.5) \\
&- 0.3867\ (10^{-11})\ (9500)\ (10500)\ (500{,}000) \\
&+ 0.1507\ (10^{-6})\ (9500)\ (10500)\ (10.0) \\
&- 0.1886\ (10^{-6})\ (9500)\ (10500)\ (7.25)
\end{aligned}
$$

$$+ 1.443\ (4.0)\ (4.1)\ (7.25)$$

$$- 0.1514\ (4.0)\ (4.1)\ (128)$$

$$- 232.1\ \frac{(9500)\ (36.5)}{(10500)\ (34.5)}$$

$$= 30 \text{ trips/day}$$

9. Total daily truck trips in the transportation study area - Model X

Y = 149700 truck trips/day - Figure 20

The development of travel patterns for a city would be performed on a computer and in addition to a tabulation of the data, a display of the data would undoubtedly be made using desire line charts. The development of travel patterns is a time consuming, repetitive process and the resulting total travel pattern data are voluminous. As a consequence only sample results from some of the models are given.

Freeway Usage

An estimate of the number of vehicle trips that will use the freeway in the example city may be determined by using the necessary data given below and the traffic assignment curves and equations previously developed:

Travel time between zone i and CBD by freeway = 8.2 min

Travel time between zone i and CBD by quickest alternate = 11.0 min

Time ratio between zone i and CBD = 0.745

Time differential between zone i and CBD = +2.8 min

Travel distance between zone i and CBD by freeway = 5.5 mi

Travel distance between zone i and CBD by quickest alternate = 4.6 mi

Distance ratio between zone i and CBD = 1.20

Distance differential between zone i and CBD = - 0.9 mi

Travel time between zone j and CBD by freeway = 7.6 min

Travel time between zone j and CBD by quickest alternate = 11.0 min

Time ratio between zone j and CBD = 0.69

Time differential between zone j and CBD = + 3.4 min

Travel distance between zone j and CBD by freeway = 5.1 mi

Travel distance between zone j and CBD by quickest alternate = 4.6 mi

Distance ratio between zone j and CBD = 1.11

Distance differential between zone j and CBD = - 0.5 mi

Travel time between zone i and zone j by freeway = 13.4 min

Travel time between zone i and zone j by quickest alternate = 17.1 min

Time ratio between zone i and zone j = 0.78

Time differential between zone i and zone j = +3.7 min

Travel distance between zone i and zone j by freeway = 8.9 mi

Travel distance between zone i and zone j by quickest alternate = 10.0 mi

Distance ratio between zone i and zone j = 0.89

Distance differential between zone i and zone j = + 1.1 mi

By using the data above and the model utilizing time and distance ratios and differentials previously developed (Model IX), the percent of freeway usage with the indicated interchange locations may be determined. Sample calculations follow:

Freeway usage between zone i and CBD

$$Y = + 0.097 + 3.33\ (.745) - 4.29\ (.745)^2 + 1.46\ (.745)^3$$

$$- 0.156\ (1.20) + 0.051\ (+ 2.8) - 0.002\ (2.8)^3 - 0.040\ (- 0.9)$$

$$= 0.75 = 75\%\ \text{usage}$$

Freeway usage between zone j and CBD

$$Y = +\ 0.097 + 3.33\ (0.69) - 4.29\ (0.69)^2 + 1.46\ (0.69)^3$$
$$-\ 0.156\ (1.11) + 0.051\ (3.4) - 0.002\ (3.4)^3$$
$$-\ 0.040\ (-\ 0.5)$$
$$= 0.78 = 78\%\text{ usage}$$

Freeway usage between zone i and zone j

$$Y = +\ 0.097 + 3.33\ (0.78) - 4.29\ (0.78)^2 + 1.46\ (0.78)^3$$
$$-\ 0.156\ (0.89) + 0.051\ (3.7) - 0.002\ (3.7)^3$$
$$-\ 0.040\ (1.1)$$
$$= 0.68 = 68\%\text{ usage}$$

Using the percentages above and the volume of trips previously determined as movements between each of the zones, the following use of the freeway by the trips between any two of these three zones is obtained:

Number of freeway vehicle trips per day between zone i and CBD
= 0.75 x 1484 = 1113

Number of freeway vehicle trips per day between zone j and CBD
= 0.78 x 1501 = 1171

Number of freeway vehicle trips per day between zone i and zone j
= 0.68 x 30 = 20

Interchange Location

As in the typical city, the central business district of the example city was the largest traffic generator. As this was also the area of greatest congestion, the location of the interchange at the central business district was determined so as to serve this area as efficiently as possible. This last location is the one shown on Figure 22.

The volume of vehicle trips at the design hour that would use the interchange at this location is

$$
\begin{aligned}
V &= V_I + V_{EI} \\
&= K^1 \sum_{1}^{99} Y^1 + 0.029\, K^1 \sum_{1}^{99} Y^1
\end{aligned}
$$

Where:

V_I = Number of internal vehicle trips at the design hour that would use the interchange.

V_{EI} = Number of external-internal trips, that is, local trips at the design hour that would use the interchange. For this example, an estimate of 2.9 percent of the internal trips was used.

K^1 = the percent of hourly traffic divided by the annual average daily traffic for the design hour at the central business district.

Y^1 = the vehicle trips per day in both directions between a zone and the CBD that use the freeway.

The volume of vehicle trips at the design hour that would use any interchange on the example freeway would be

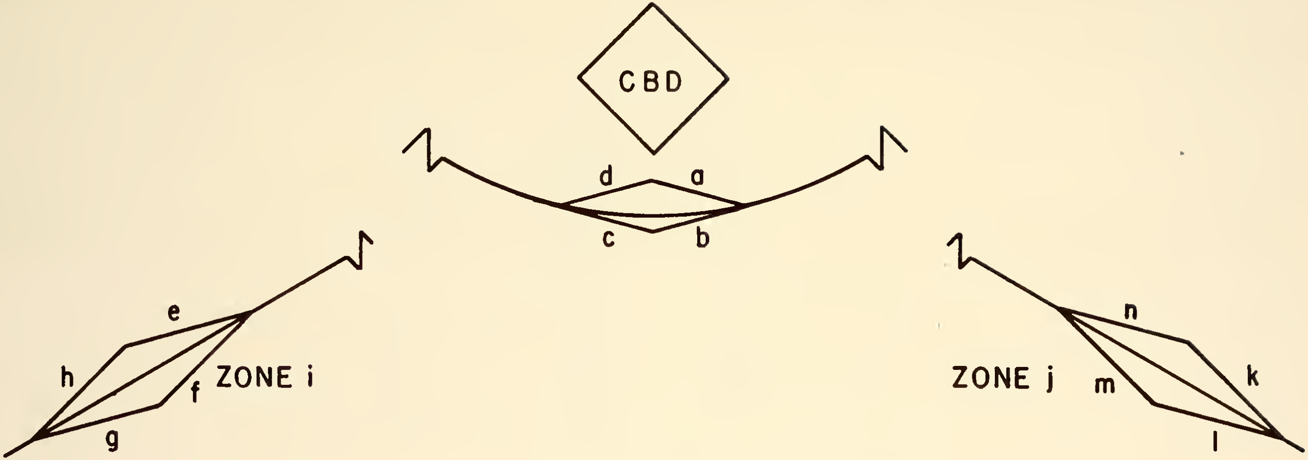
$$
\begin{aligned}
V_i &= V_I + V_{EI} \\
&= K_i \left[\sum_{1}^{4851} Y + \sum_{1}^{99} Y^1 \right] + 0.029\, V_I \\
&= 1.029 \quad K_i \left(\sum_{1}^{4851} Y + \sum_{1}^{99} Y^1 \right)
\end{aligned}
$$

Where:

K_i = the percent of hourly traffic divided by the annual average daily traffic for the design hour at interchange i.

Y = the vehicle trips per day in both directions between two zones that use the freeway.

Figure 23 illustrates sample volume calculations on the appropriate interchange ramps of this example. A distribution factor, previously discussed, must be applied to the calculated design hour volume for each appropriate pair of ramps at each interchange to determine the volume on a single ramp.



VEHICULAR VOLUME ON RAMPS a & b = $1.029\,[.10(\cdots+1171+\cdots)]$

VEHICULAR VOLUME ON RAMPS c & d = $1.029\,[.10(\cdots+1113+\cdots)]$

VEHICULAR VOLUME ON RAMPS e & f = $1.029\,[.10(\cdots+20+1113+\cdots)]$

VEHICULAR VOLUME ON RAMPS m & n = $1.029\,[.10(\cdots+20+1171+\cdots)]$

FIG. 23 SAMPLE VOLUME CALCULATIONS ON INTERCHANGE RAMPS

A comparison is then necessary of the volume - capacity relationship that exists for each interchange. In those locations where future volume on each ramp of an interchange is less than the capacity of a ramp lane adjacent interchanges may be grouped if warranted by an economic analysis. Relocation of some interchanges will necessitate new volume calculations because of changes in travel times and distances. This procedure would be continued until the most economical design and location of the interchanges is found.

In those interchange locations where future volume is greater than ramp lane capacity, the following alternatives are possible.

1. Increase capacity by the addition of more ramp lanes.
2. Through long range planning, decrease volume by control of the various factors that contribute to trip production.
3. Utilize other modes of transportation.
4. Add another interchange. Through innovations in interchange design and freeway operation, it may be possible to construct interchanges closer than the desirable minimum of one mile and still have proper traffic operations integrated with safety.

The number of interchanges should be neither minimized nor maximized as it is the function of the freeway - to serve the public, road-user, and land owner in a safe, efficient manner - which should be maximized.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

These conclusions are applicable to the major urban areas within standard metropolitan statistical areas of less than one million population.

A. The following travel pattern elements or characteristics can be reliably estimated for a transportation study area by use of the indicated models developed in this research:

   1. The total number of vehicle trips per day - Model I (page 26)
   2. The ratio of external vehicle trips per day to total vehicle trips per day - Model II (page 30)
   3. The ratio of local vehicle trips per day to internal vehicle trips per day - Model III (page 30)
   4. The number of vehicle trips per day to and from the central business district - Model IV (page 34)
   5. The number of intrazonal central business district vehicle trips per day - Model V (page 43)
   6. The total number of vehicle trips per day attracted and generated by each zone - Model VI (page 71)
   7. The number of vehicle trips per day between a zone and the central business district - Model VII (page 75)

8. The number of interzonal vehicle trips per day between two zones, excluding the CBD zone - Model VIII (page 76)

B. The central business district is the largest generator of trips within the transportation study area.

C. The usage of a freeway is best estimated by Model IX (page 97)

D. The number of truck trips per day in a transportation study area can be reliably estimated by the use of Model X (page 111)

E. A good estimate of the design hour volume (30th highest hour) is ten (10) percent of the average daily traffic volume.

Recommendations for Further Study

The following items are recommended for further investigation:

1. A comparison of results obtained by using the various models with data collected from a completed transportation study in a city other than the ones used in this study.
2. The development of similar models for cities not in standard metropolitan statistical areas.
3. The annual changes, if any, and factors causing the changes in the various travel pattern characteristics of urban areas.

Models for trip prediction will not supplant all field studies in urban areas but models are a tool that can assist in the understanding of urban transportation problems. It is imperative that continuing studies be made so that travel patterns in urban areas can be thoroughly understood by the transportation planner.

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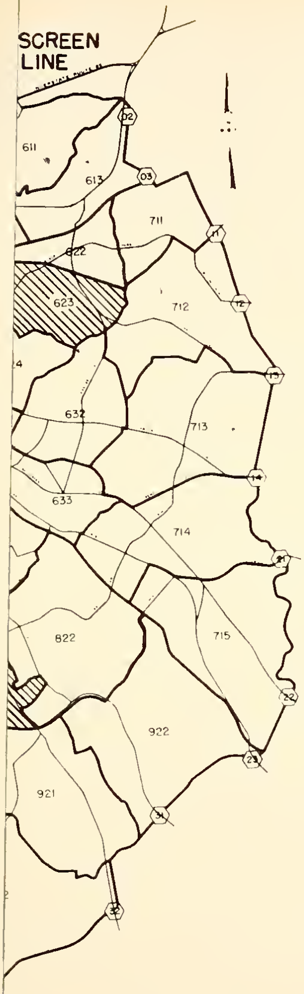
APPENDIX A



INA TRANSPORTATION

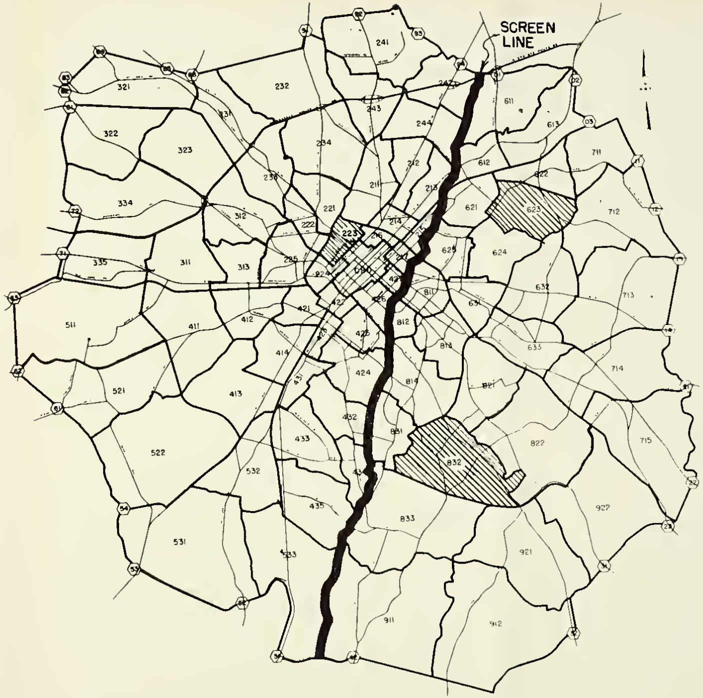
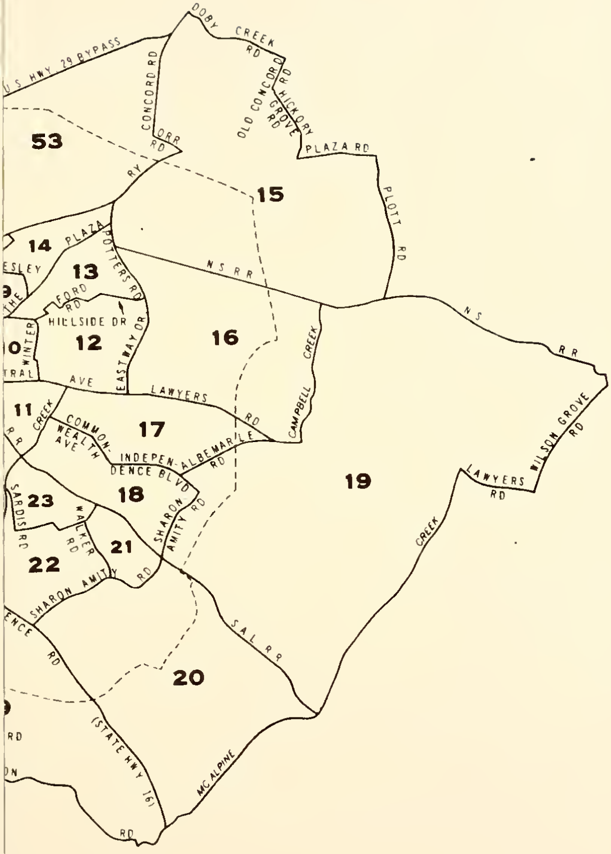


FIG. A-1 CHARLOTTE, NORTH CAROLINA TRANSPORTATION STUDY AREA



60 CENSUS TRACTS

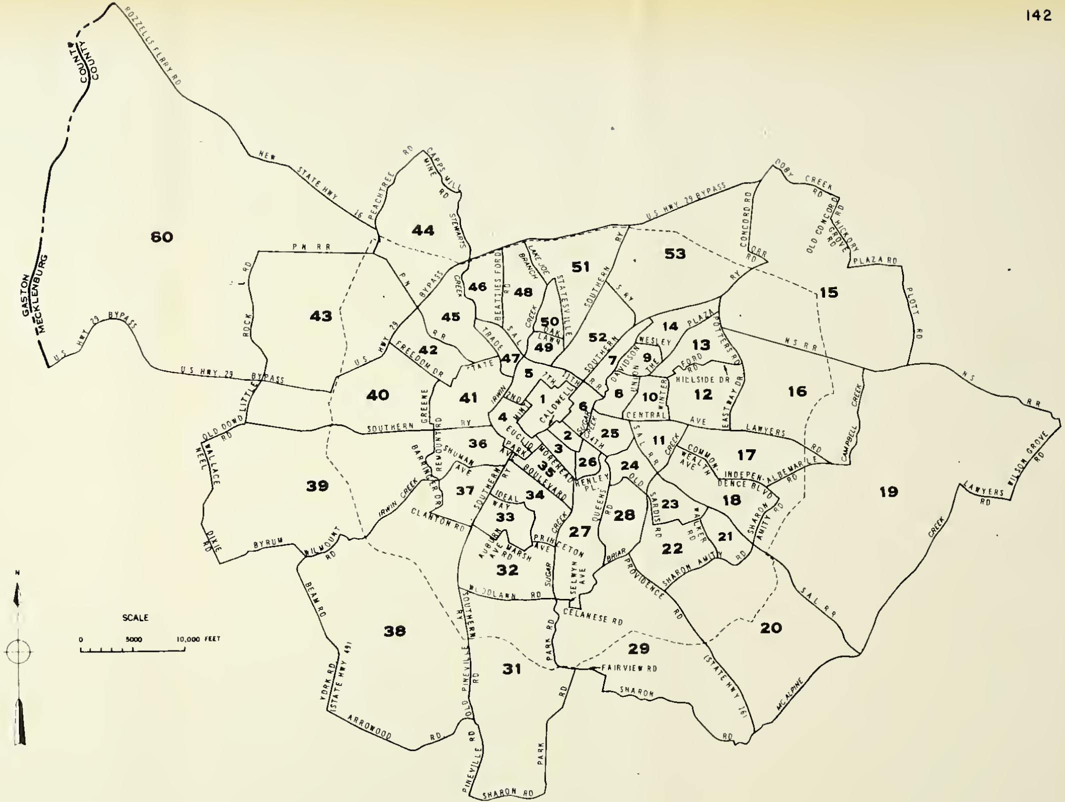


FIG. A-2 CHARLOTTE, NORTH CAROLINA 1960 CENSUS TRACTS

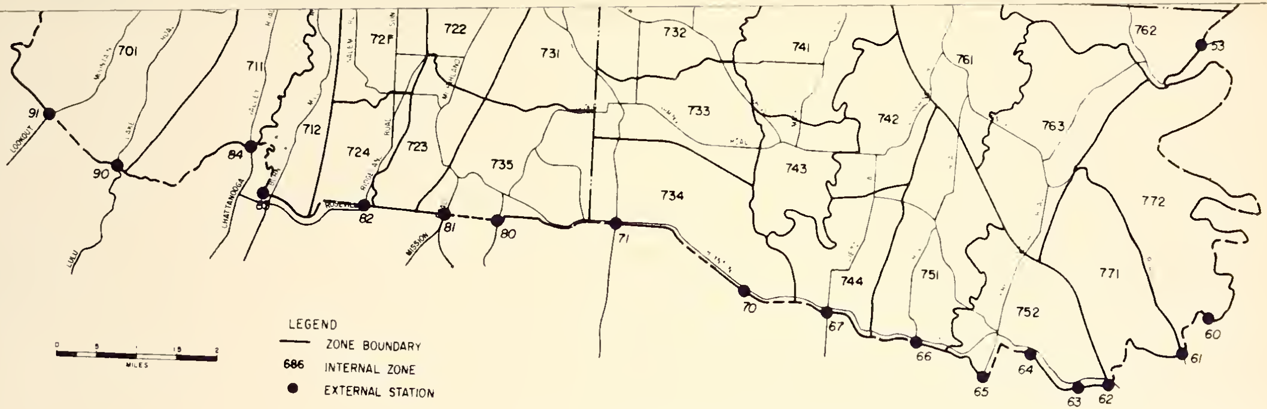


FIG. A-3 CHATTANOOGA, TENNESSEE TRANSPORTATION STUDY AREA

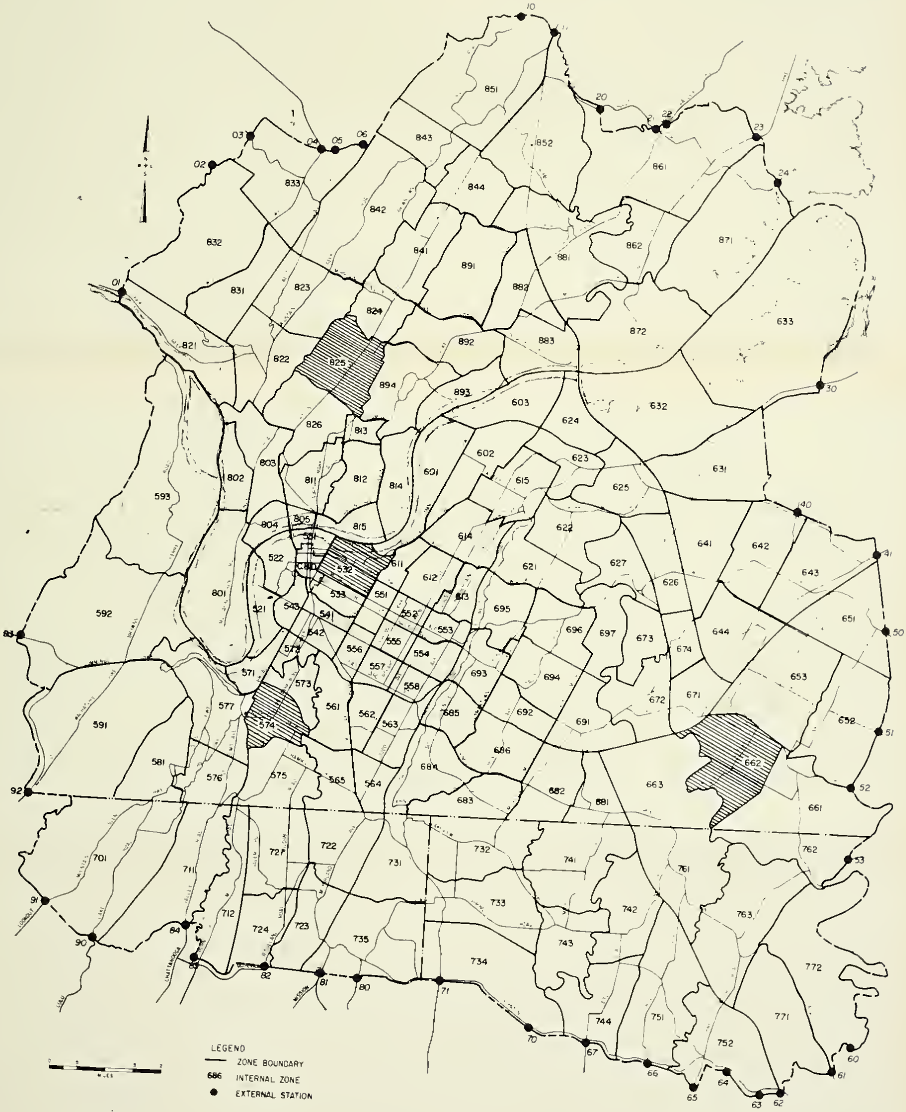


FIG. A-3 CHATTANOOGA, TENNESSEE TRANSPORTATION STUDY AREA

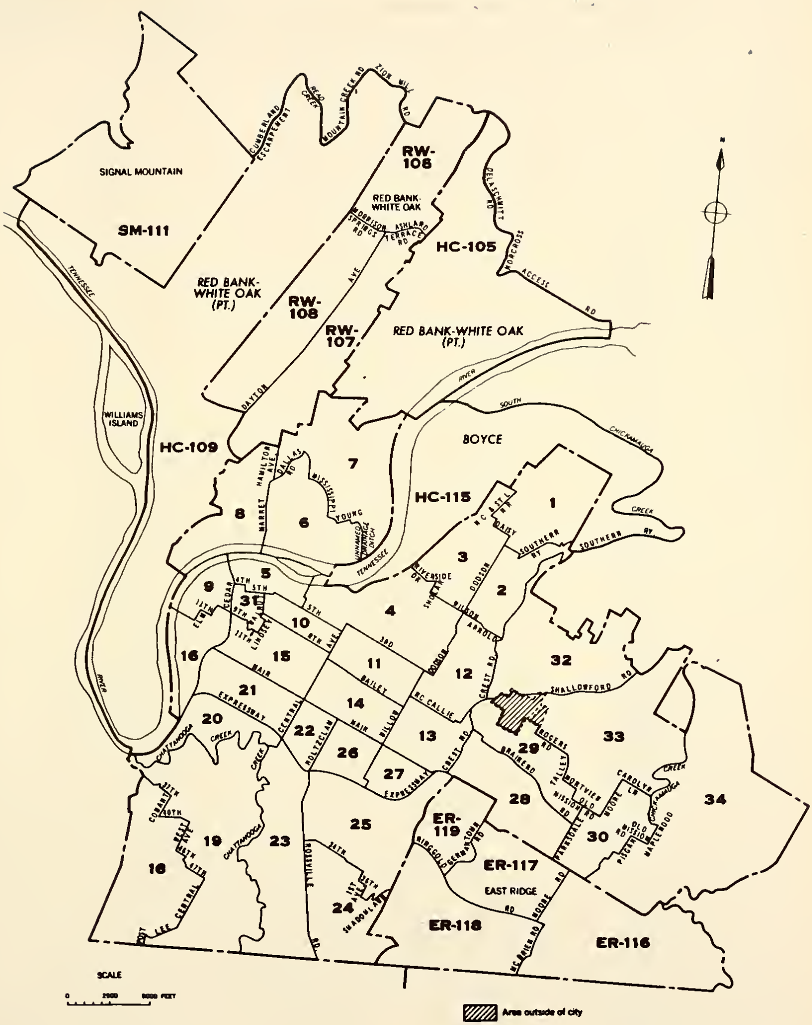


FIG. A-4 CHATTANOOGA, TENNESSEE 1960 CENSUS TRACTS

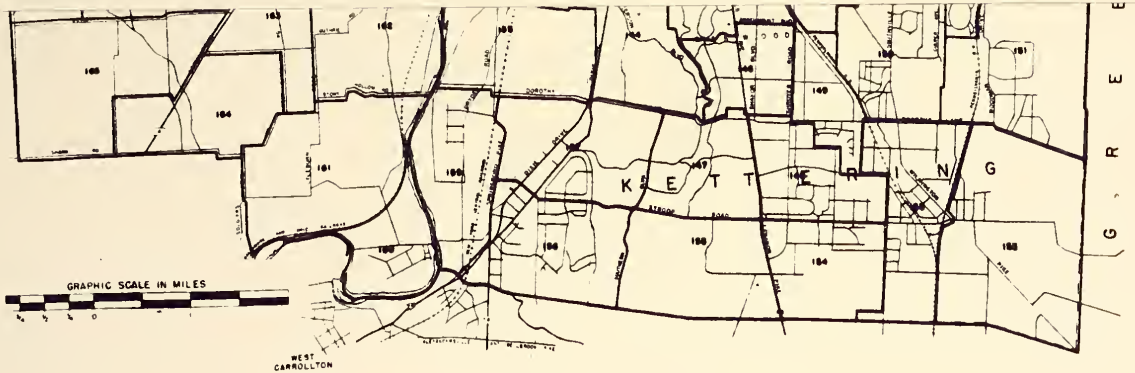


FIG. A-5 DAYTON, OHIO TRANSPORTATION STUDY AREA

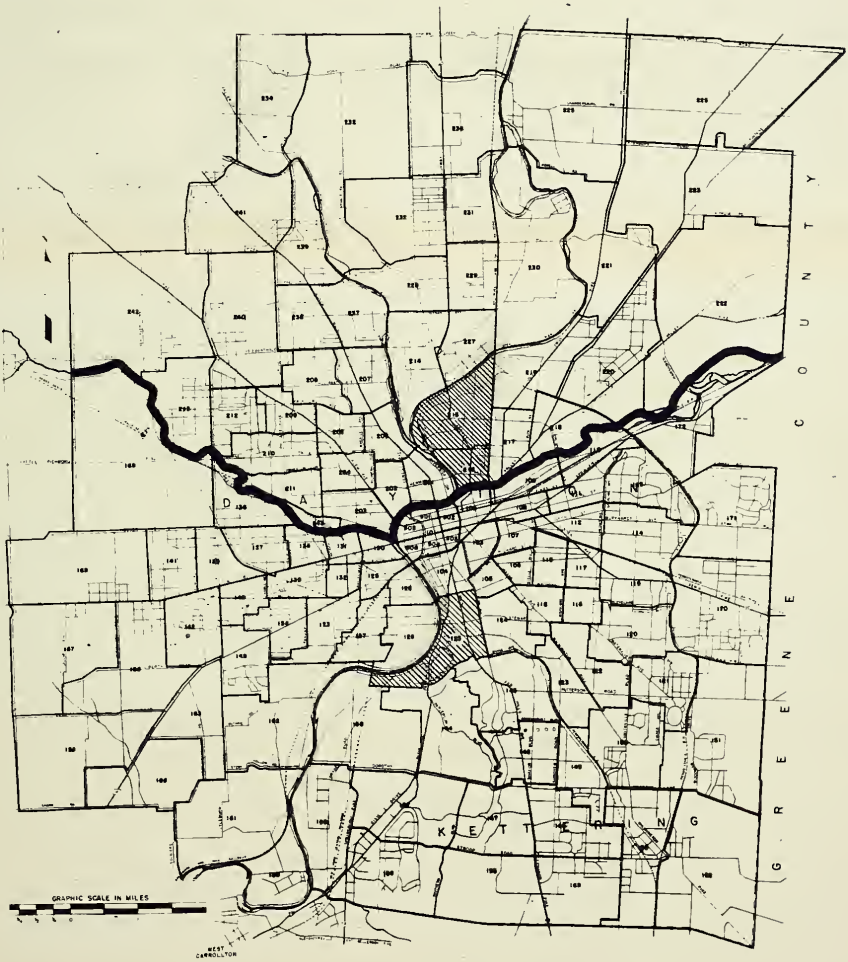


FIG. A-5 DAYTON, OHIO TRANSPORTATION STUDY AREA

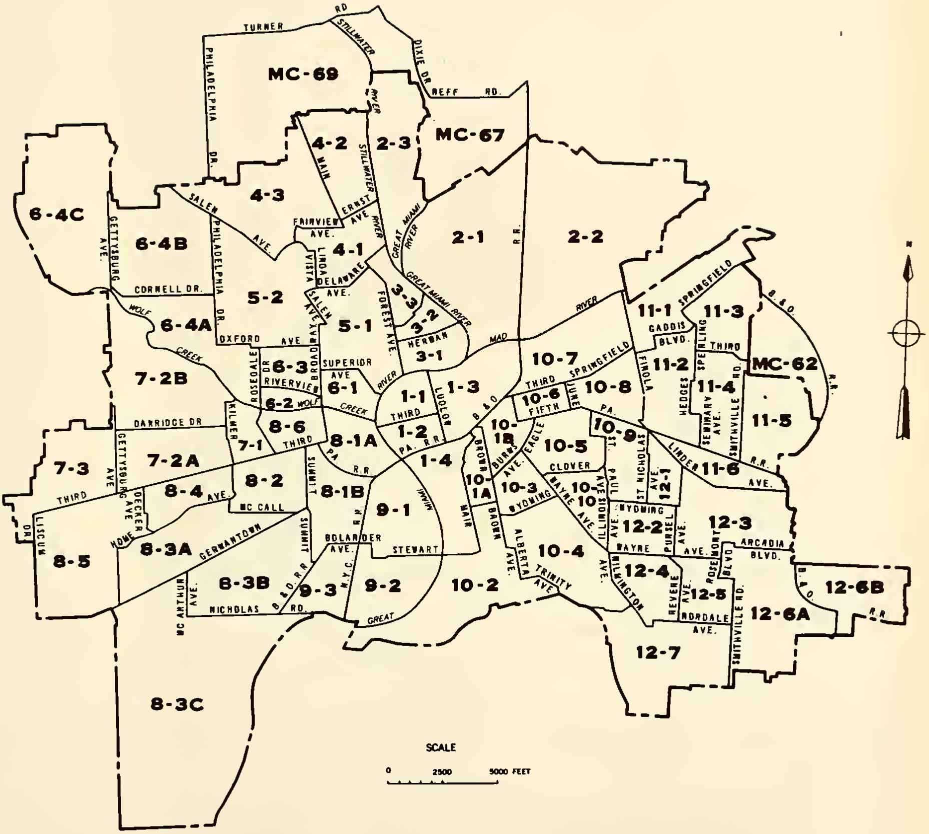


FIG. A-6 DAYTON, OHIO 1960 CENSUS TRACTS

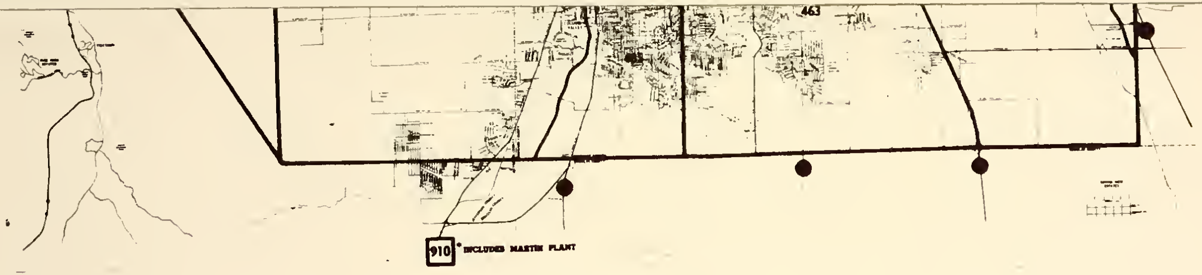


FIG. A-7 DENVER, COLORADO TRANSPORTATION STUDY AREA

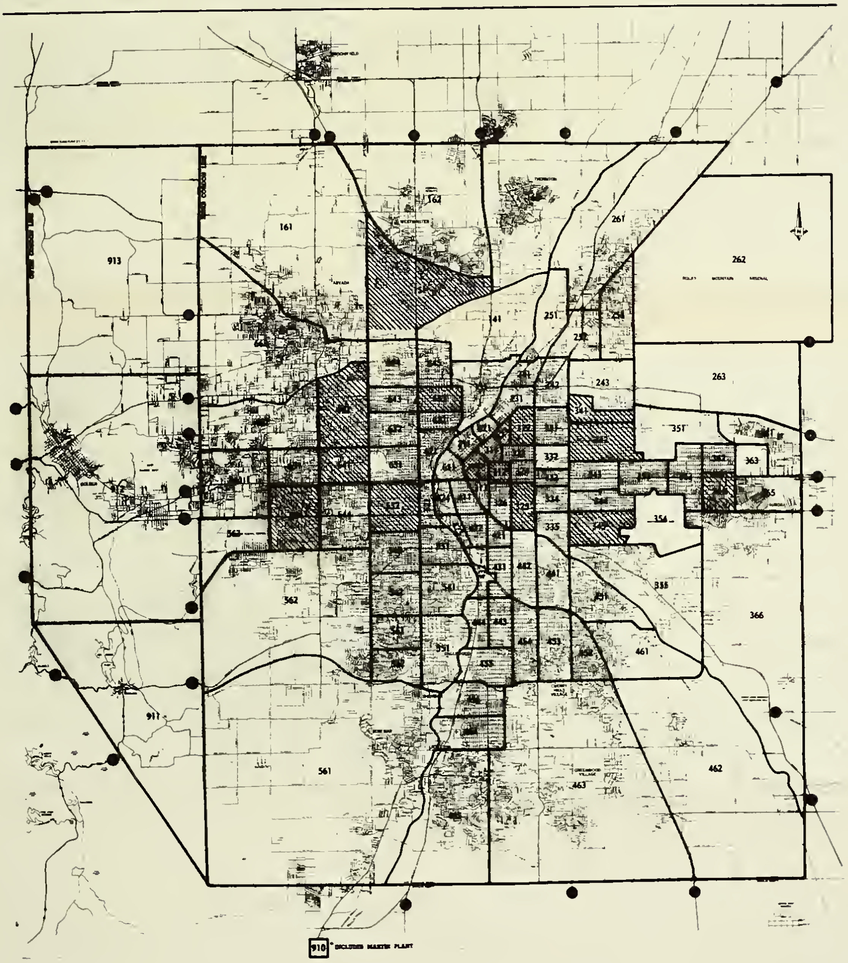


FIG. A-7 DENVER, COLORADO TRANSPORTATION STUDY AREA

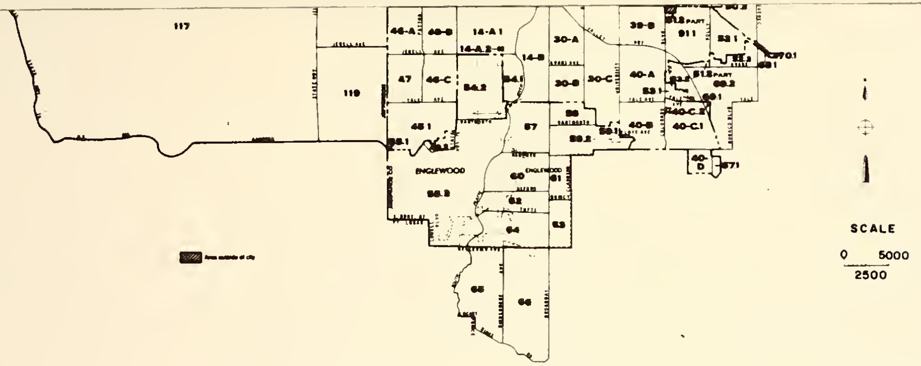


FIG. A-8 DENVER, COLORADO 1960 CENSUS TRACTS

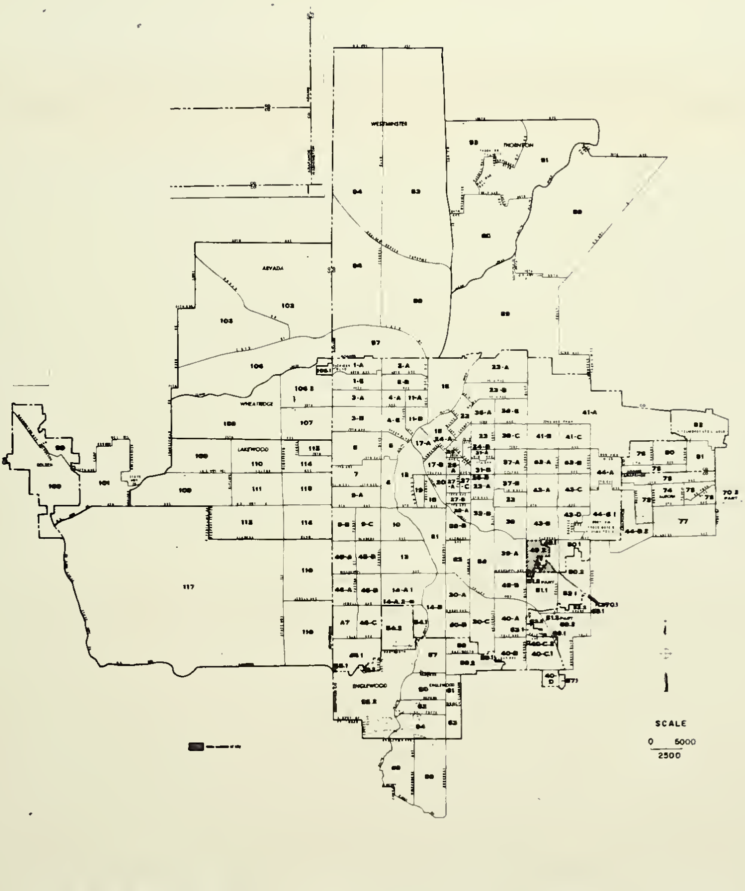


FIG. A-8 DENVER, COLORADO 1960 CENSUS TRACTS

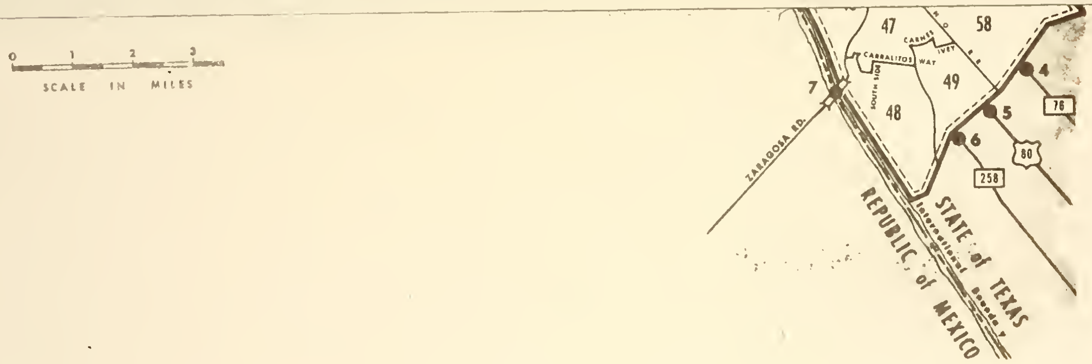


FIG. A-9 EL PASO, TEXAS TRANSPORTATION STUDY AREA

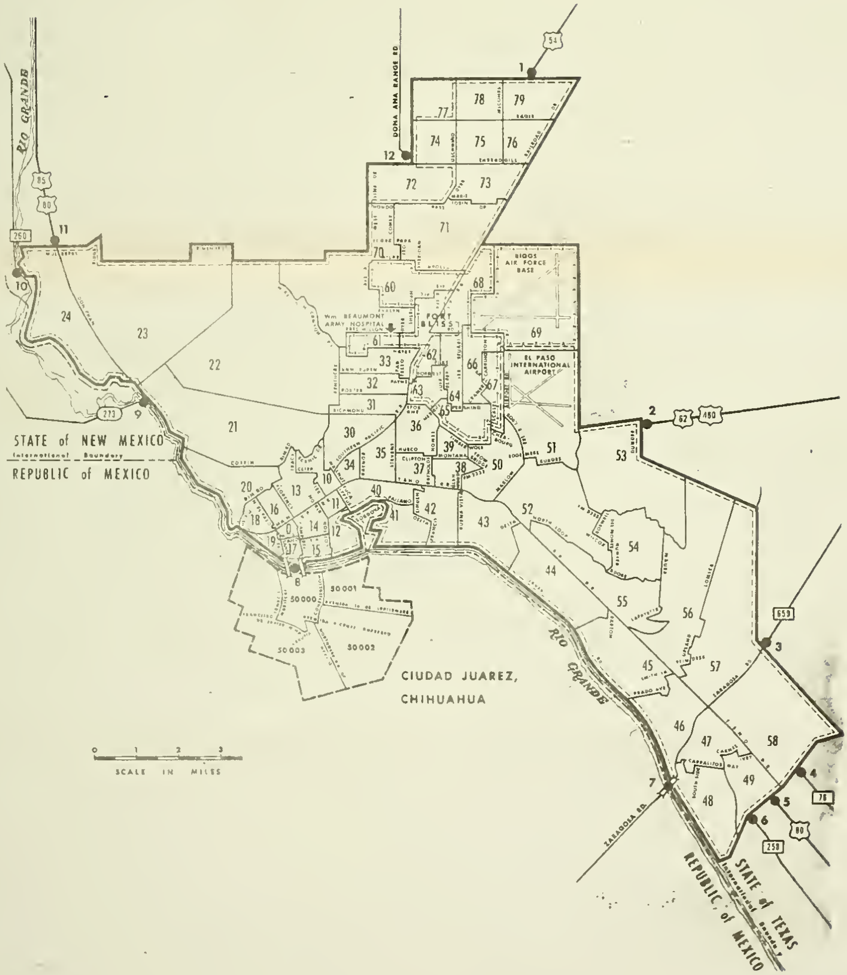


FIG. A-9 EL PASO, TEXAS TRANSPORTATION STUDY AREA

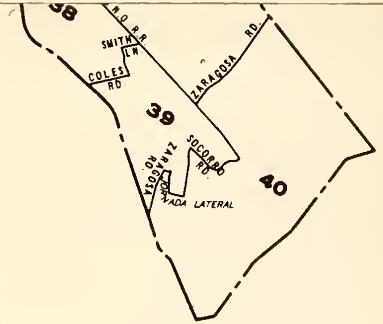


FIG.A-10EL PASO TEXAS 1960 CENSUS TRACT

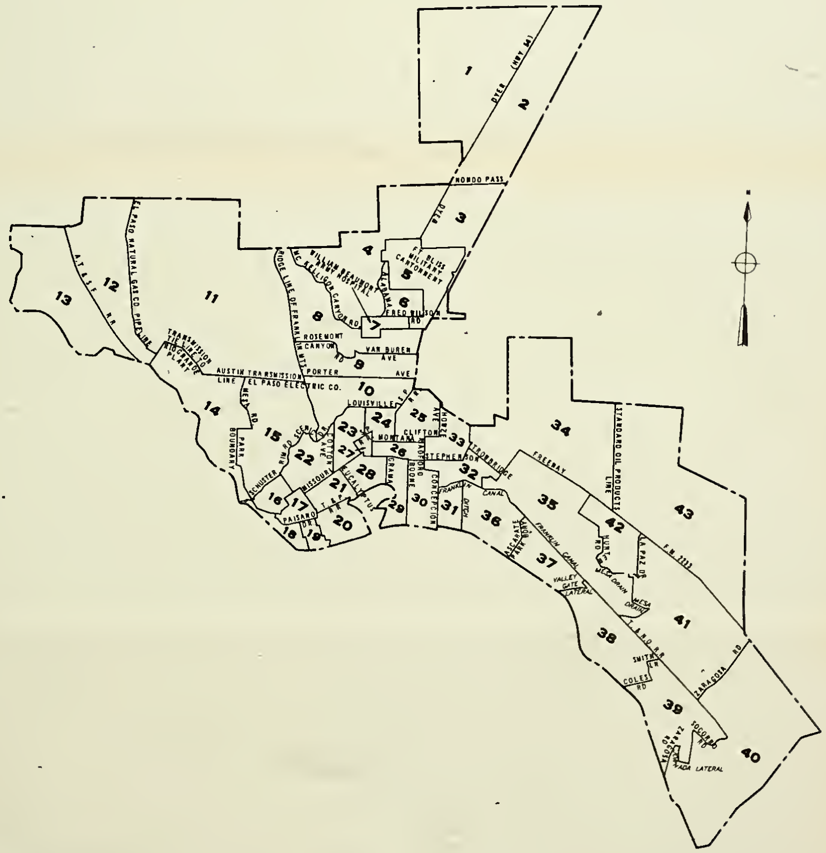


FIG.A-10 EL PASO TEXAS 1960 CENSUS TRACT

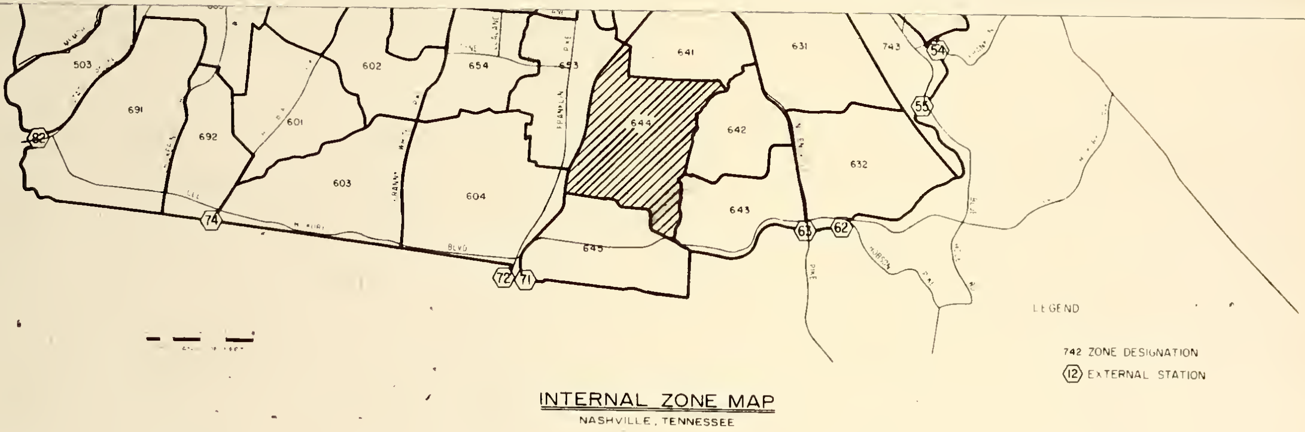


FIG. A-11 NASHVILLE, TENNESSEE TRANSPORTATION STUDY AREA

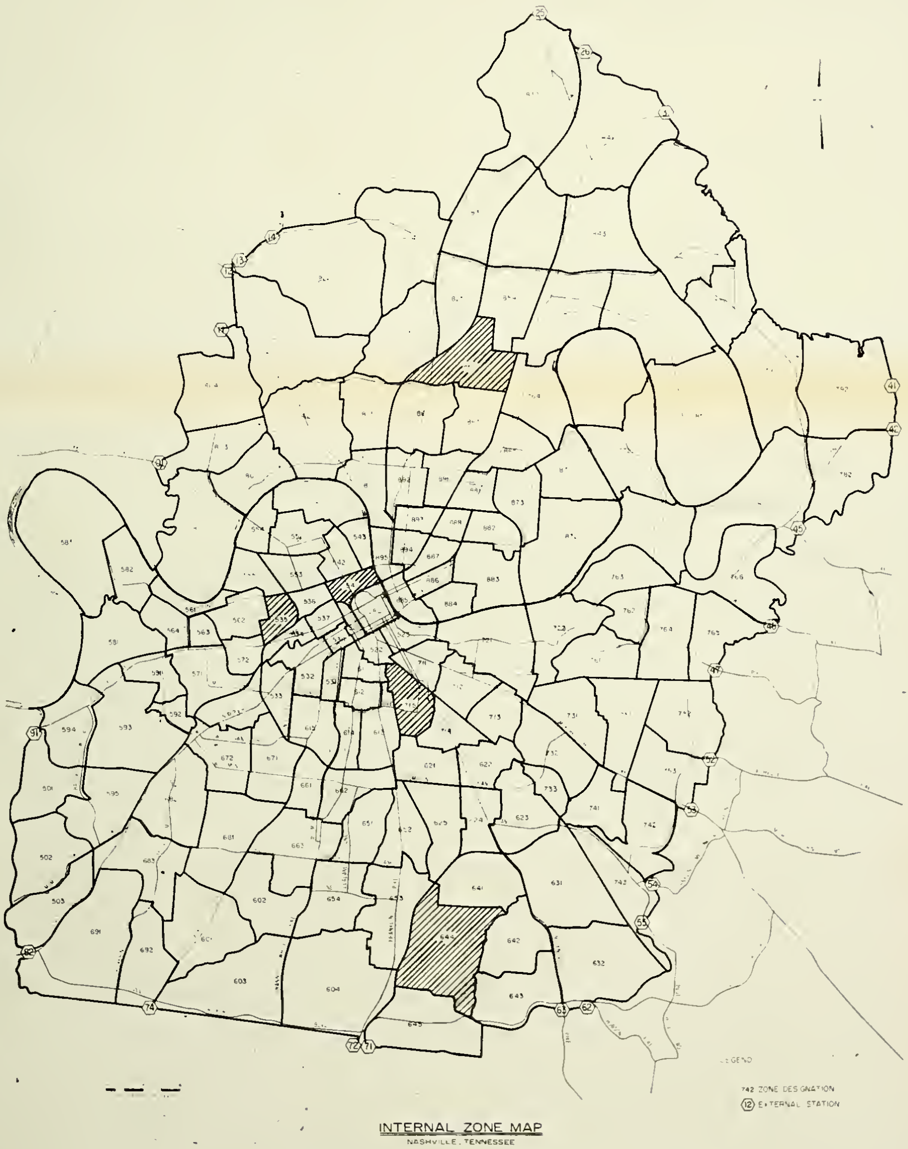


FIG. A-11 NASHVILLE, TENNESSEE TRANSPORTATION STUDY AREA

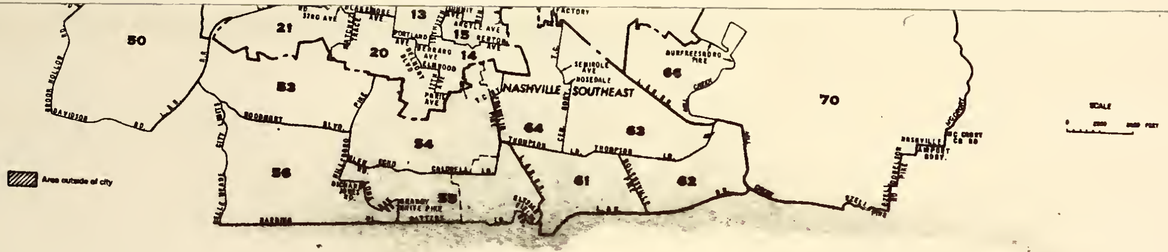


FIG.A-12 NASHVILLE, TENNESSEE 1960 CENSUS TRACTS

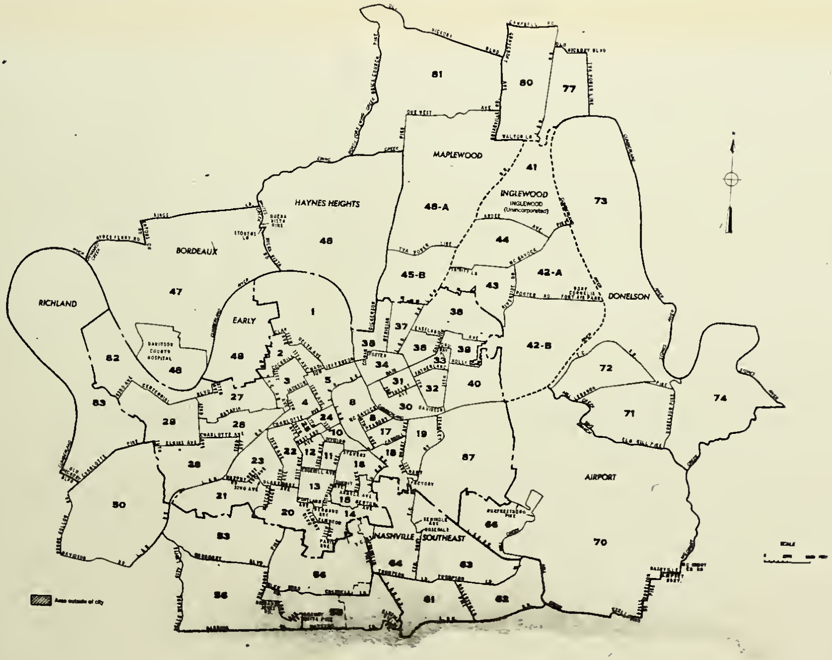
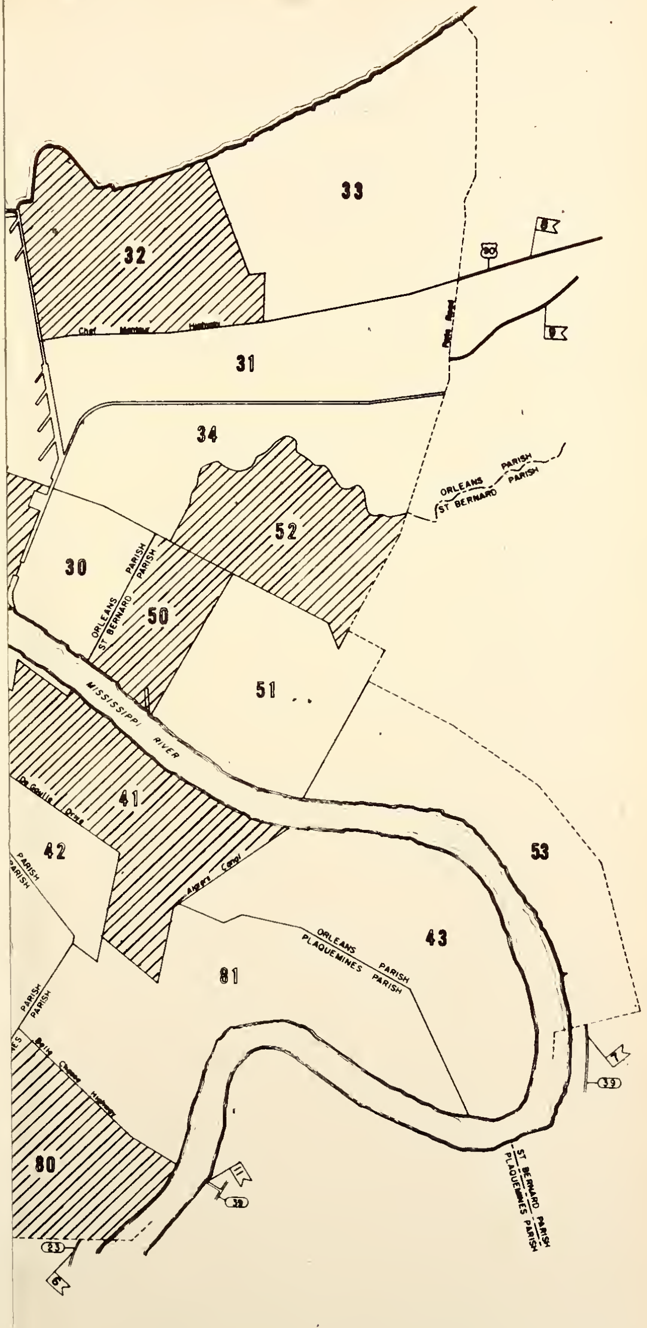


FIG.A-12 NASHVILLE, TENNESSEE 1960 CENSUS TRACTS


33
32
Chef Menteur Highway
90
31
Paris Road
34
ORLEANS PARISH
ST BERNARD PARISH
52
30
ORLEANS PARISH
ST BERNARD PARISH
50
51
MISSISSIPPI RIVER
De Gaulle Drive
41
42
PARISH
PARISH
Algiers Canal
53
ORLEANS PARISH
PLAQUEMINES PARISH
43
81
PARISH
PARISH
Belle Chasse Highway
80
39
39
23
ST BERNARD PARISH
PLAQUEMINES PARISH

REA

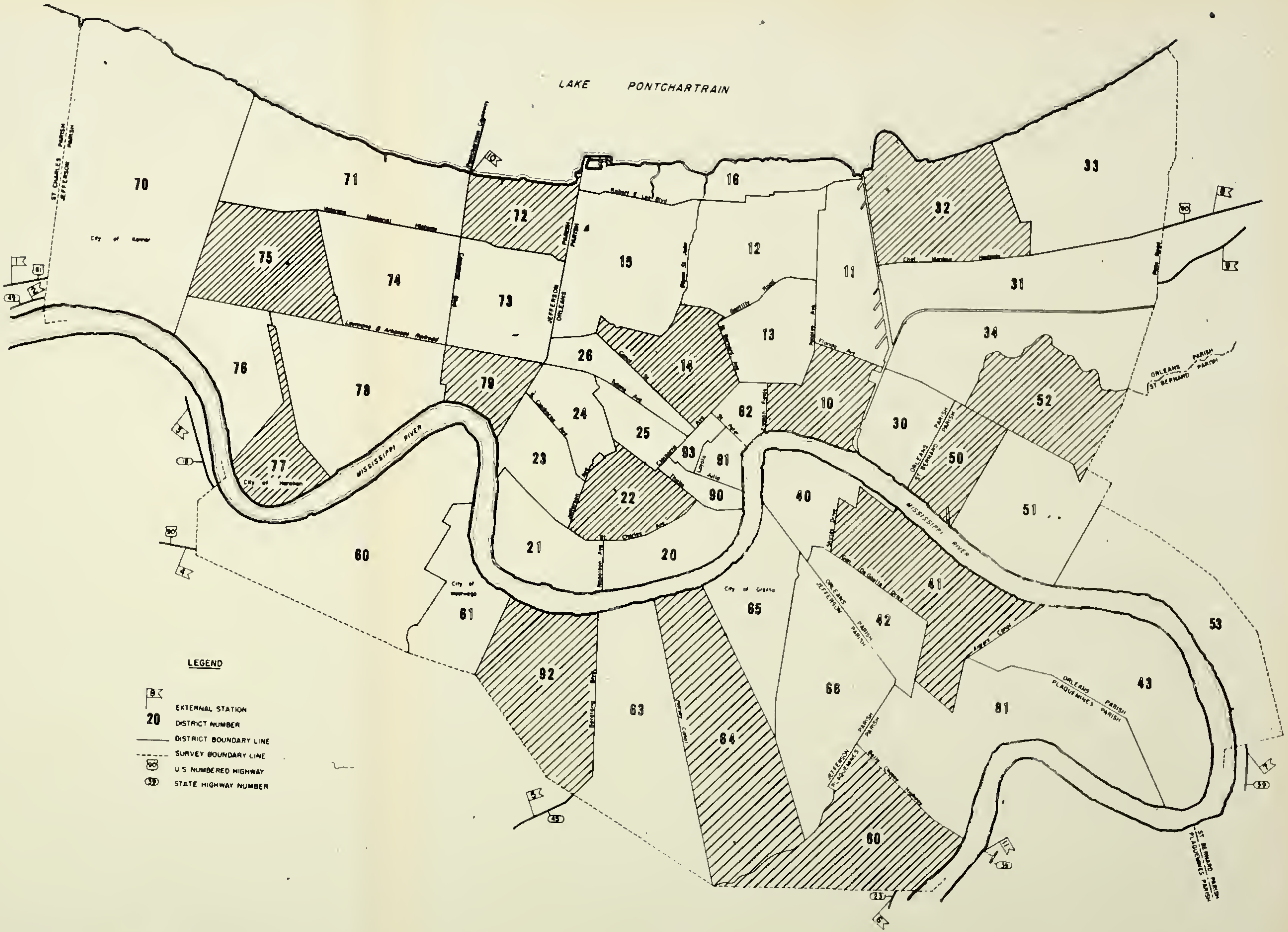
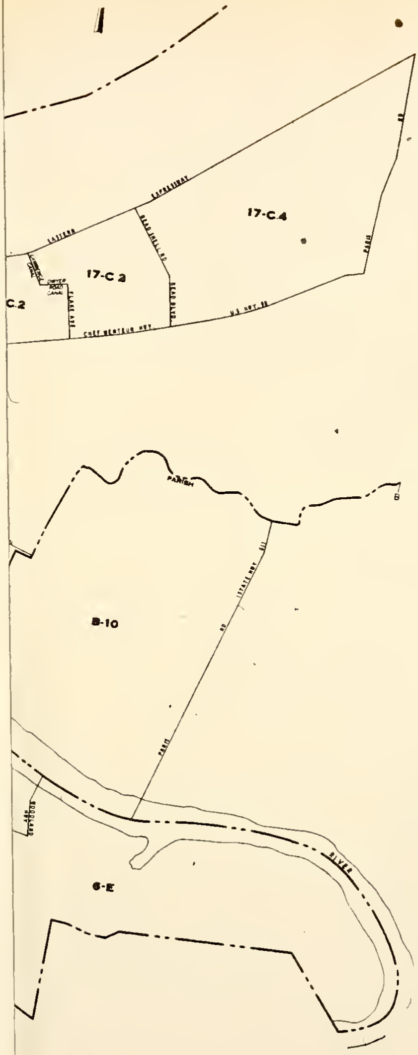


FIG. A-13 NEW ORLEANS, LOUISIANA TRANSPORTATION STUDY AREA


EASTERN
EXPRESSWAY
RD
PARIS
17-C.4
17-C.2
C.2
DWYER ROAD CANAL
CANAL
READ BLVD.
CHEF MENTEUR HWY.
U.S. HWY. 90
PARISH
B
B-10
STATE HWY
RD
PARIS
RIVER
6-E

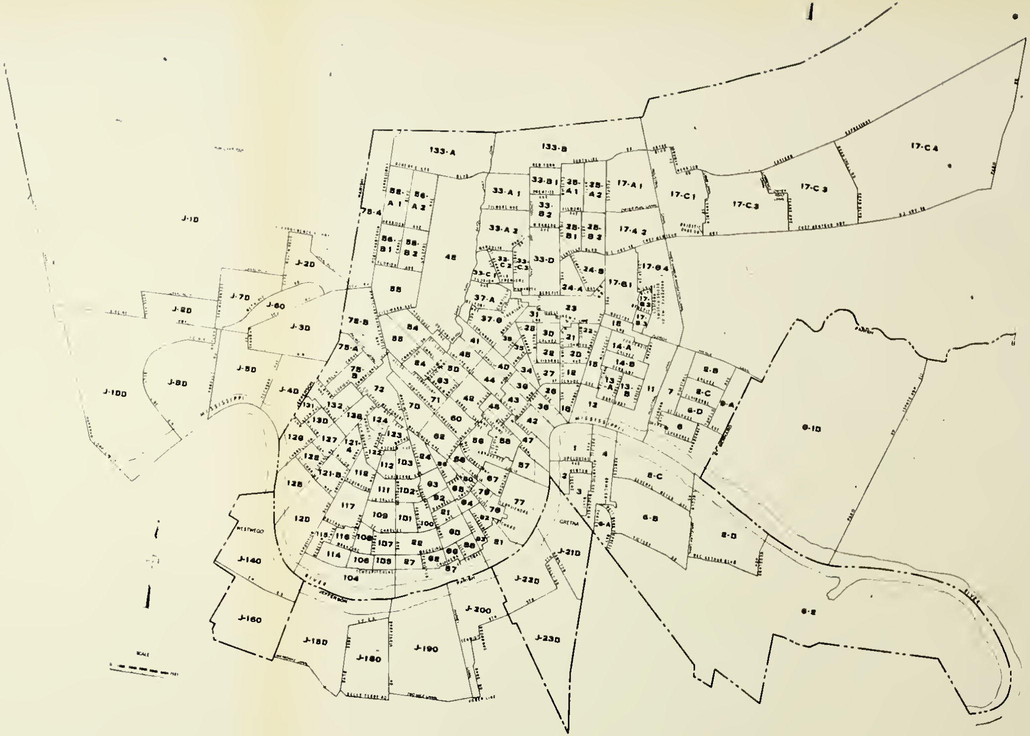


FIG. A-14 NEW ORLEANS, LOUISIANA 1960 CENSUS TRACTS

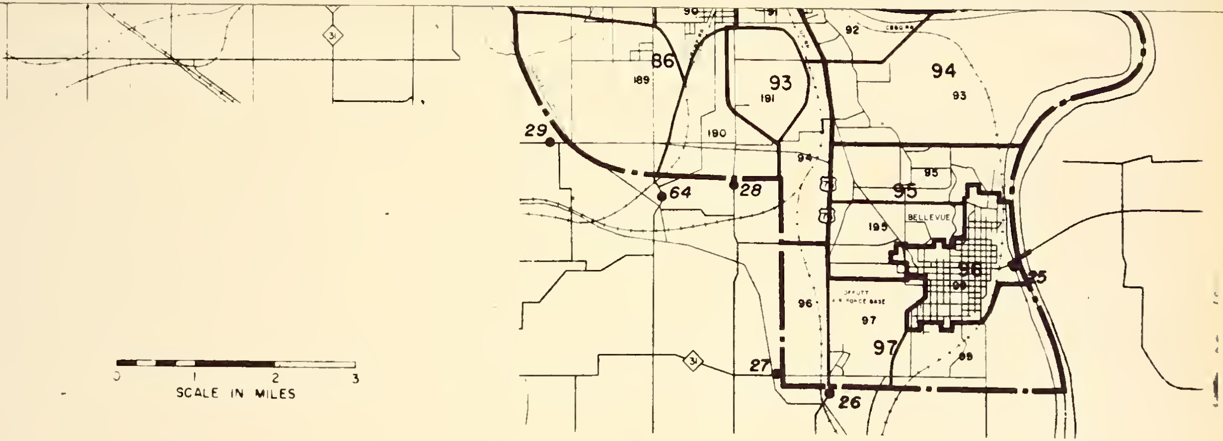


FIG.A-15 OMAHA, NEBRASKA TRANSPORTATION STUDY AREA

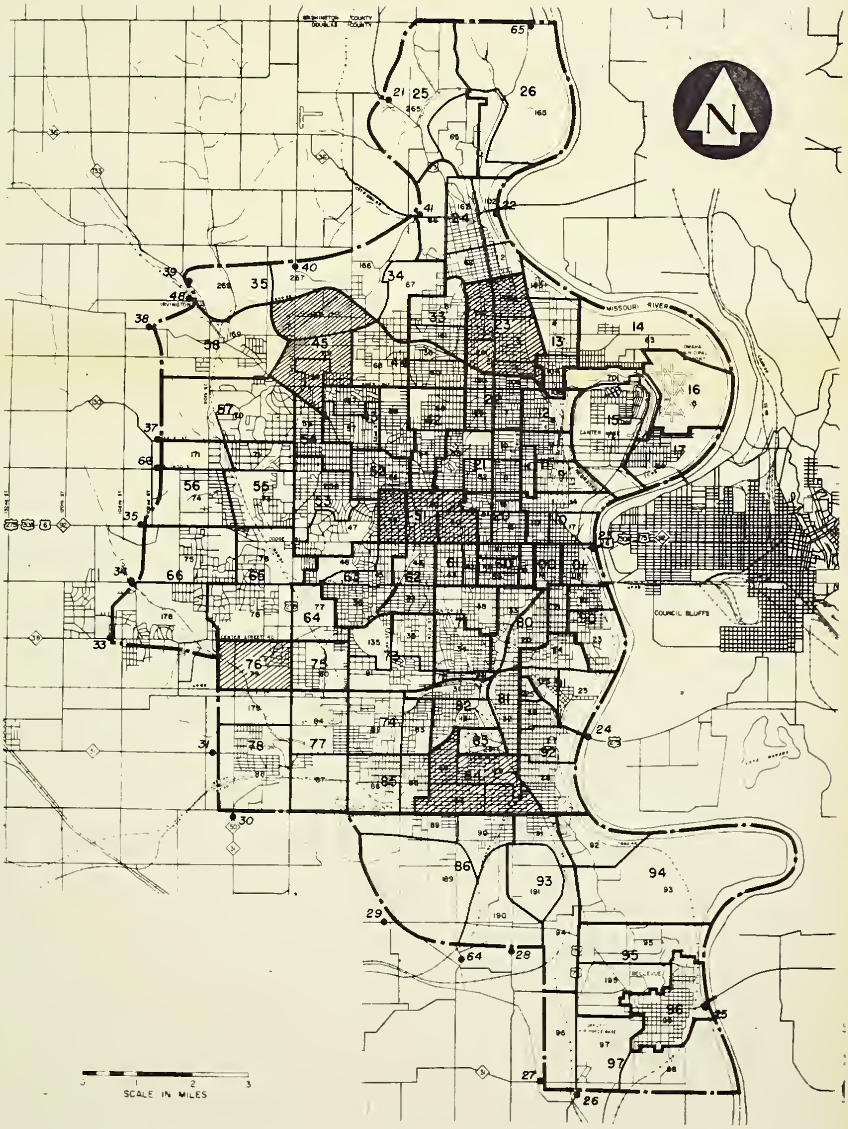


FIG.A-15 OMAHA, NEBRASKA TRANSPORTATION STUDY AREA

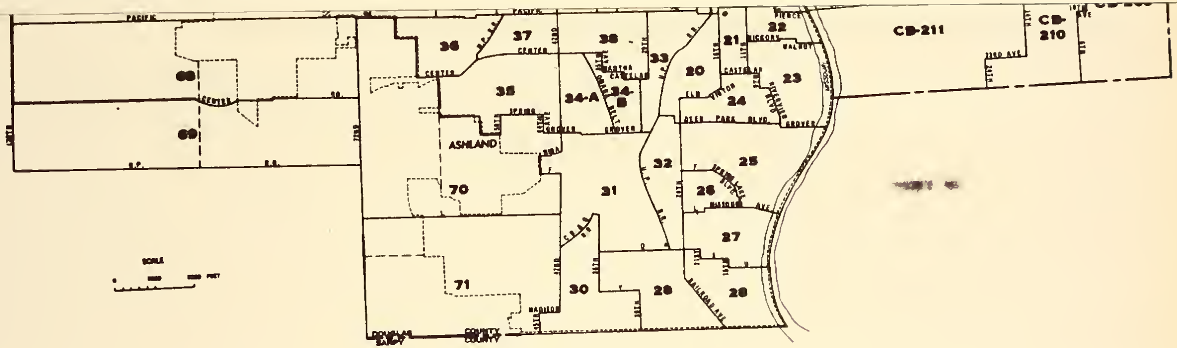


FIG.A-16 OMAHA, NEBRASKA 1960 CENSUS TRACTS

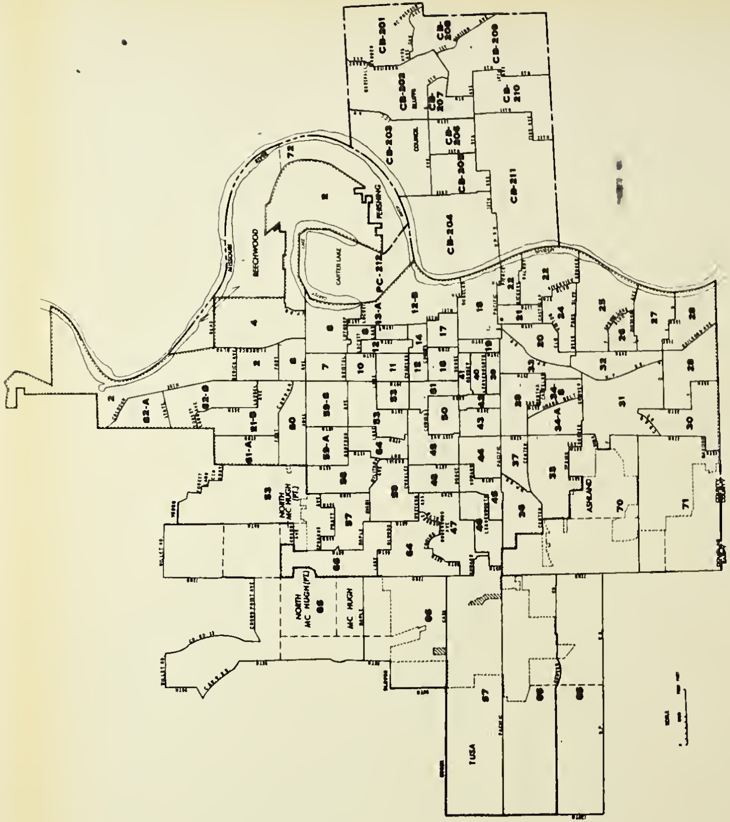
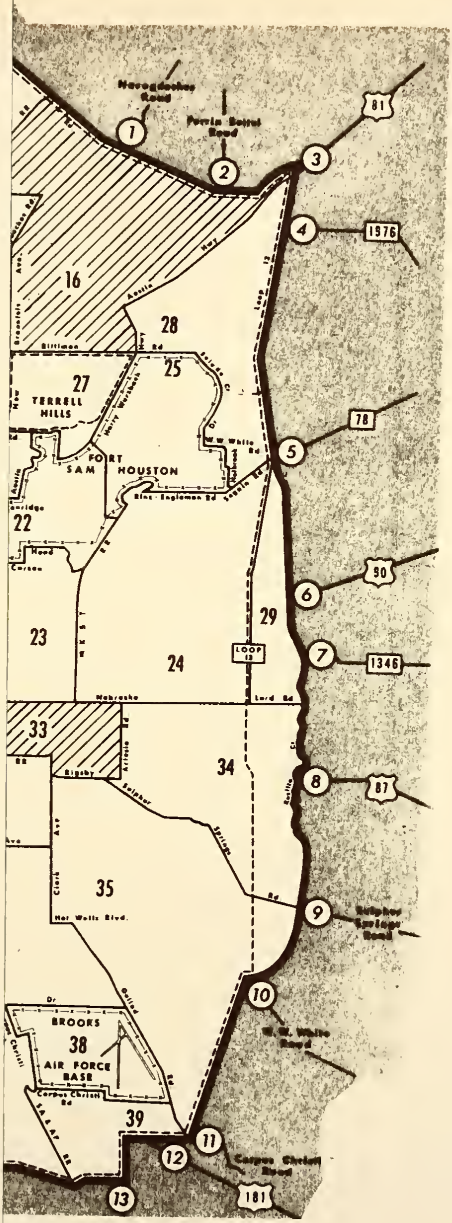


FIG.A-16 OMAHA, NEBRASKA 1960 CENSUS TRACTS


Nacogdoches Road
Perrin Beitel Road
1
2
3
4
5
6
7
8
9
10
11
12
13
81
1976
78
90
1346
87
181
16
22
23
24
25
27
28
29
33
34
35
38
39
Austin Hwy
Loop 13
LOOP 13
Braunfels Ave.
Bitters Rd
New
TERRELL HILLS
Harry Wurzbach
W W White Rd
Holbrook
FORT SAM HOUSTON
Rice - Engleman Rd
Seguin Rd
Austin
Hood
Carson
RR
Nebraska
Lord Rd
Artesia Rd
Rigsby
Sulphur Springs Rd
Rosillo Cr
Clark Ave
Ave
Hot Wells Blvd.
Goliad Rd
Dr
BROOKS AIR FORCE BASE
Corpus Christi Rd
SA & AP RR
Sulphur Springs Road
W. W. White Road
Corpus Christi Road

DY AREA

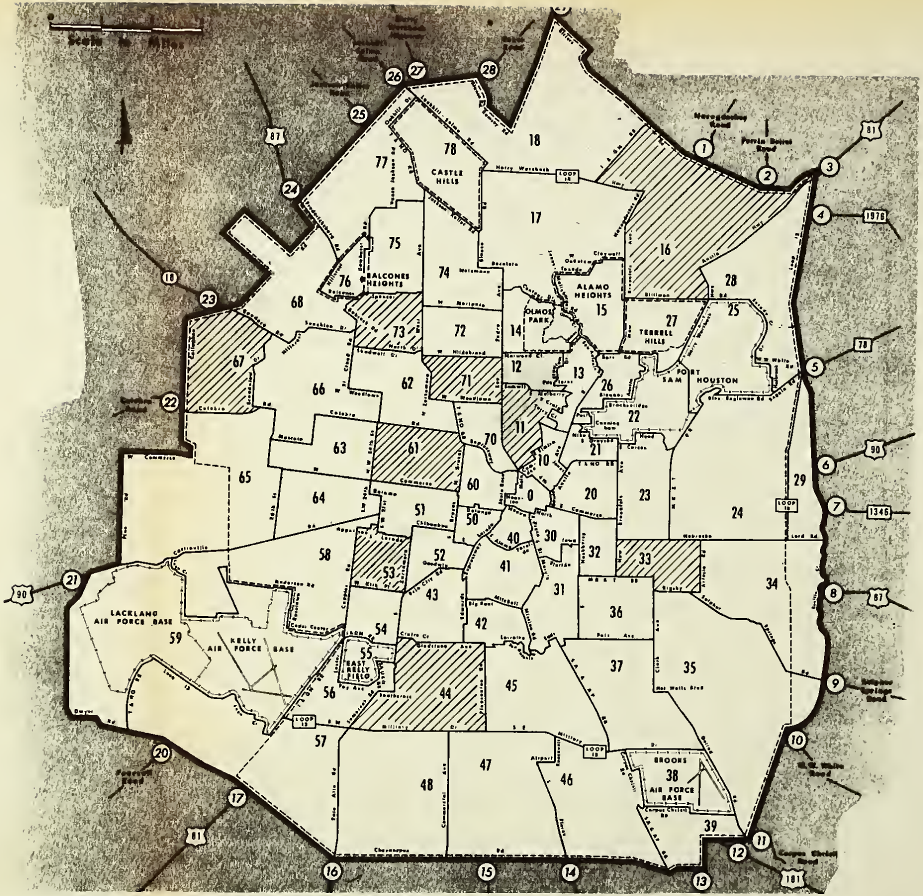
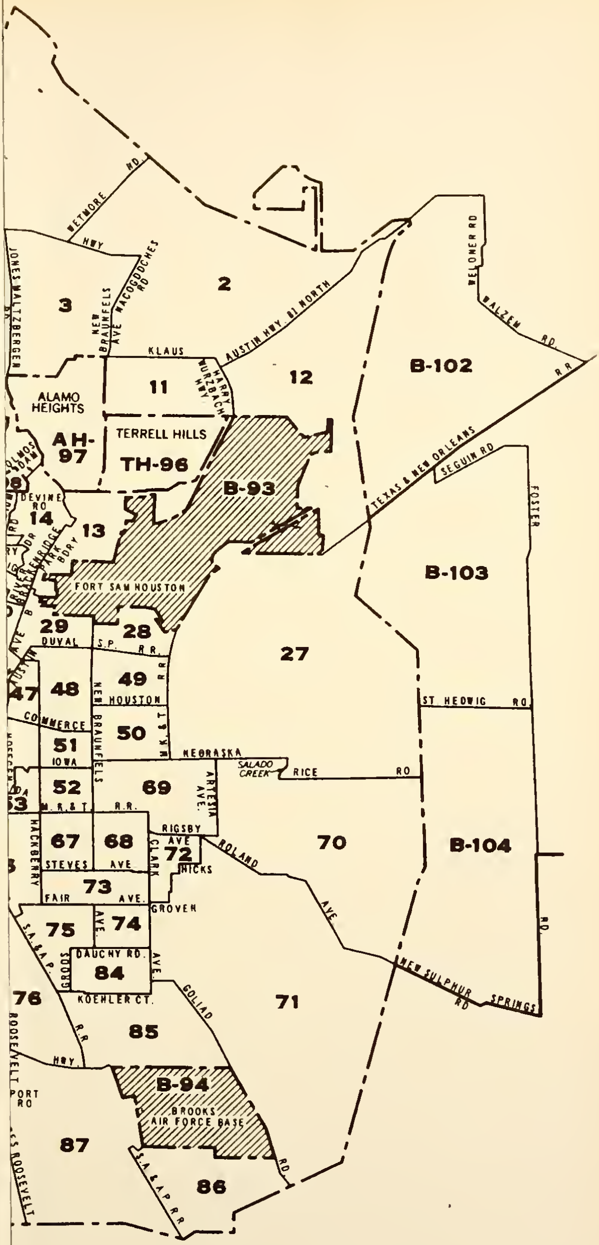


FIG.A-17 SAN ANTONIO, TEXAS TRANSPORTATION STUDY AREA


WETMORE RD
HWY
JONES MALTZBERGER RD
NEW BRAUNFELS AVE
NACOGDOCHES RD
3
2
KLAUS
AUSTIN HWY. 81 NORTH
WELONER RD
WALZEM RD
R.R.
B-102
11
12
HARRY WURZBACH HWY
ALAMO HEIGHTS
AH-97
TERRELL HILLS
TH-96
OLMOS DAM
DEVINE RD
14
13
B-93
TEXAS & NEW ORLEANS
SEGUIN RD
FOSTER RD
BRACKENRIDGE PARK
BORY
RIVER
FORT SAM HOUSTON
B-103
29
28
DUVAL
S.P. R.R.
27
AUSTIN
47
48
49
HOUSTON
NEW BRAUNFELS
COMMERCE
50
M.K.&T. R.R.
ST HEDWIG RD
51
IOWA
NEBRASKA
SALADO CREEK
RICE RD
52
69
ARTESIA AVE.
M.K.&T. R.R.
HACKBERRY
67
68
RIGSBY AVE
72
CLARK
HICKS
ROLAND AVE
70
B-104
STEVES AVE
73
FAIR AVE.
GROVEN
75
74
S.A.&A.P.
GROOS
DAUCHY RD.
84
AVE.
76
KOEHLER CT.
GOLIAD RD
NEW SULPHUR SPRINGS RD
71
R.R.
85
ROOSEVELT
HWY
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ROOSEVELT
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ACTS

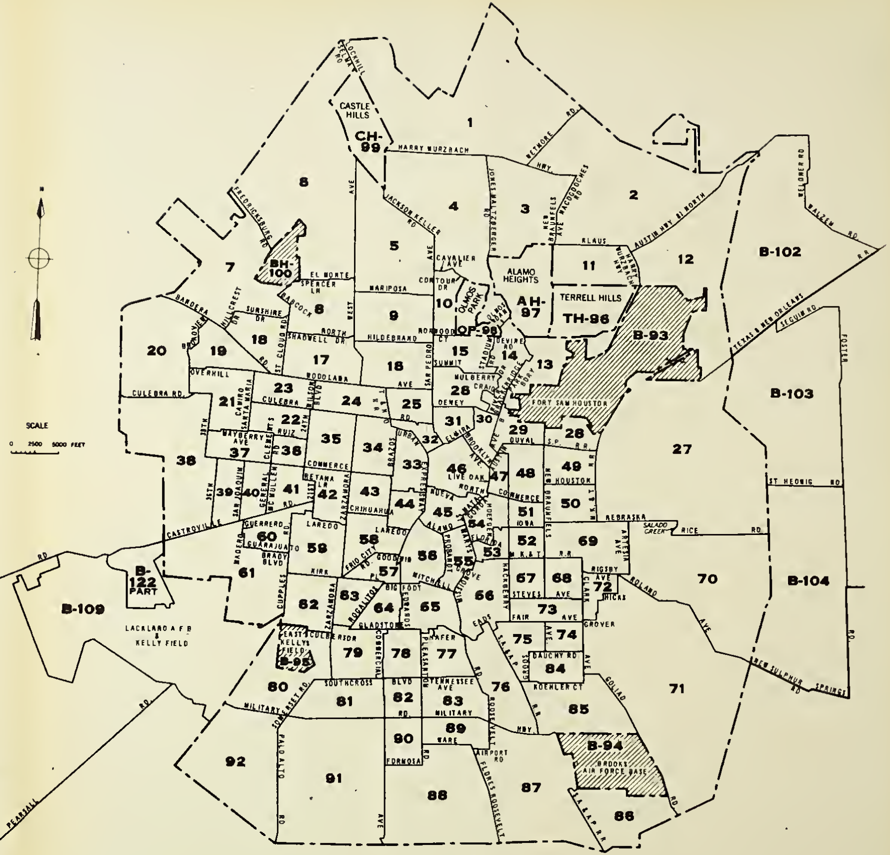
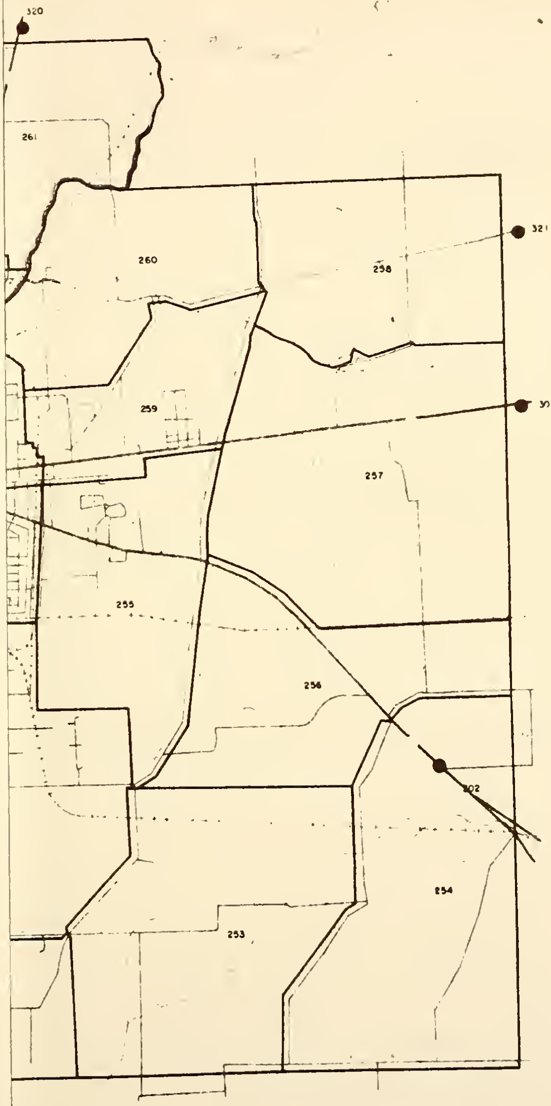


FIG.A-18 SAN ANTONIO, TEXAS 1960 CENSUS TRACTS



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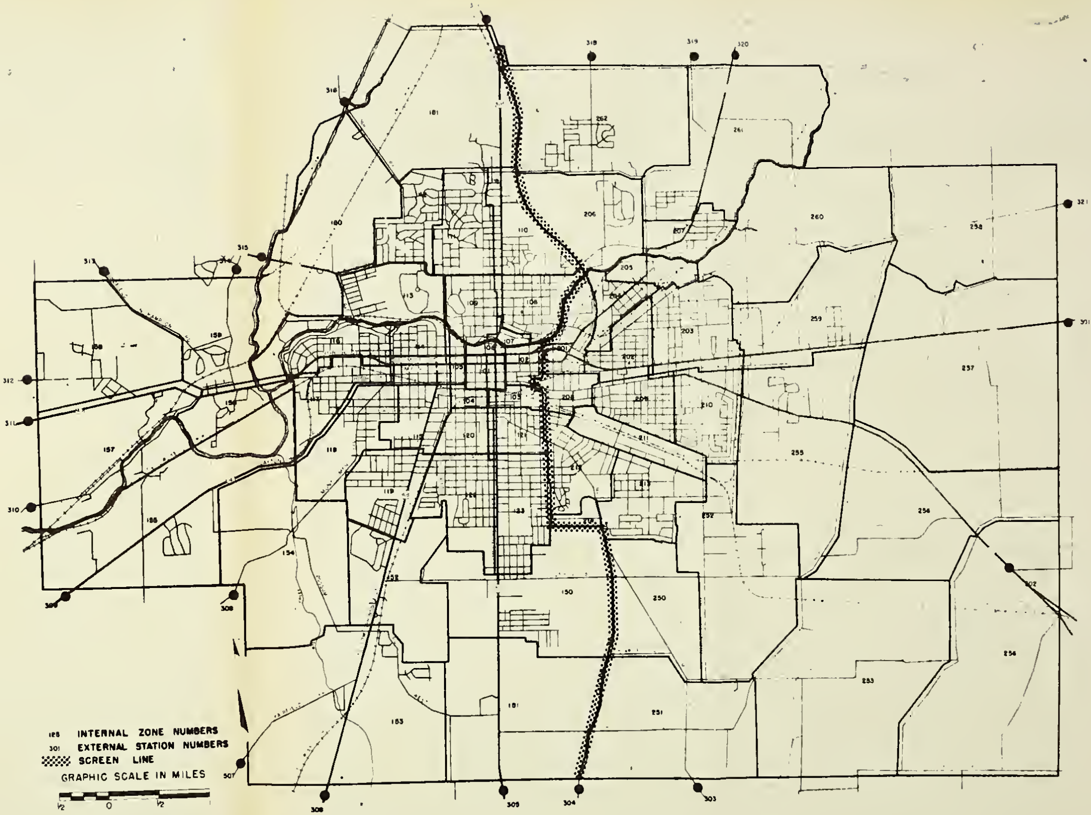
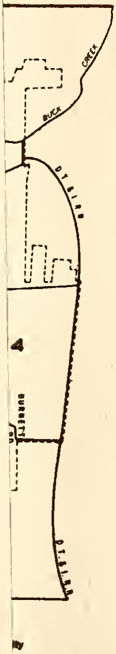


FIG.A-19 SPRINGFIELD, OHIO TRANSPORTATION STUDY AREA



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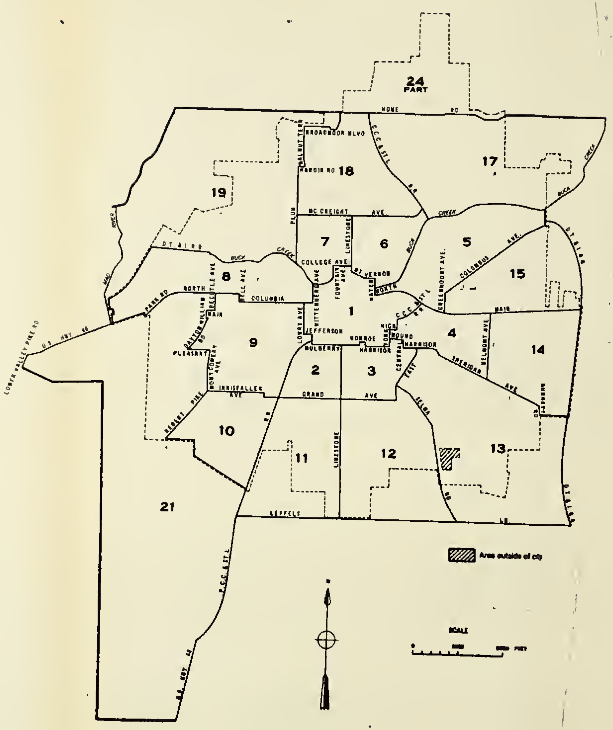
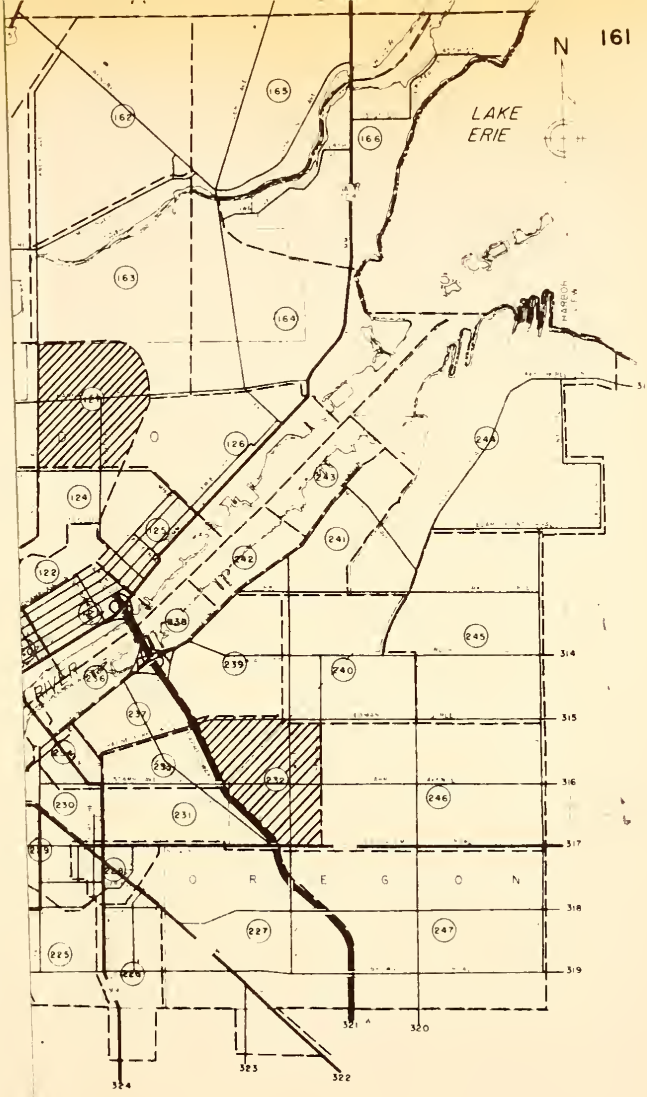


FIG.A-20SPRINGFIELD, OHIO 1960 CENSUS TRACTS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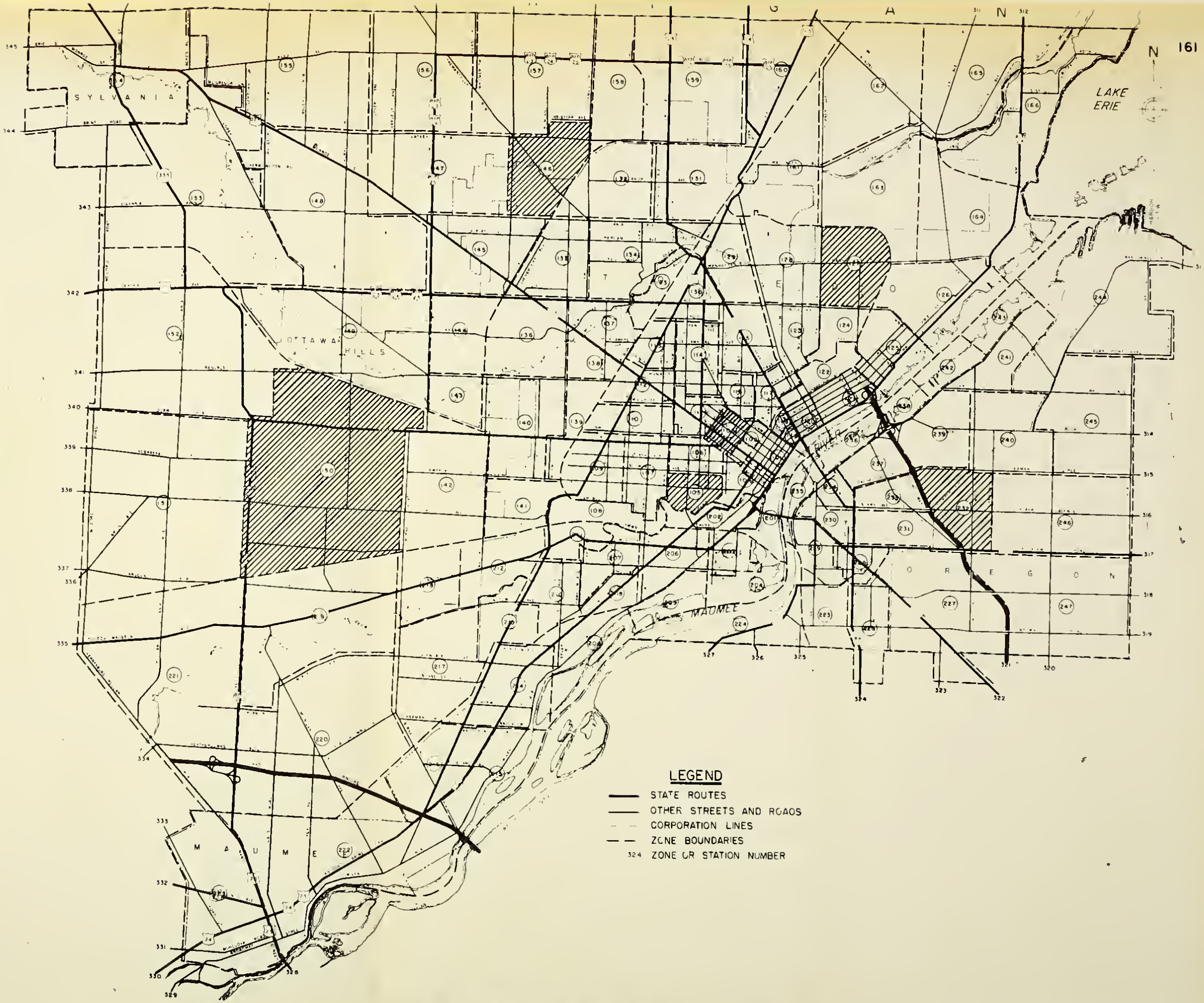
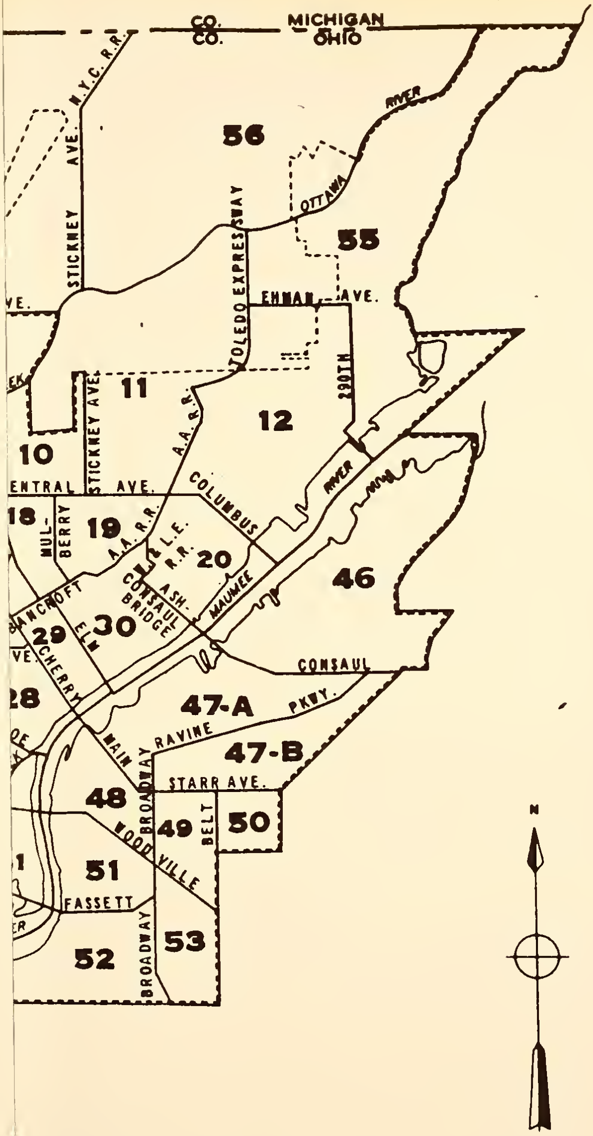


FIG.A-21 TOLEDO, OHIO TRANSPORTATION STUDY AREA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STICKNEY AVE.
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A.A. R.R.
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ENTRAL AVE.
COLUMBUS
RIVER
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MUL-BERRY
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A.A. R.R.
L.E. R.R.
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MAUMEE
CONSAUL BRIDGE
BANCROFT
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ELM
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CONSAUL
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PKWY.
RAVINE
MAIN
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BROADWAY
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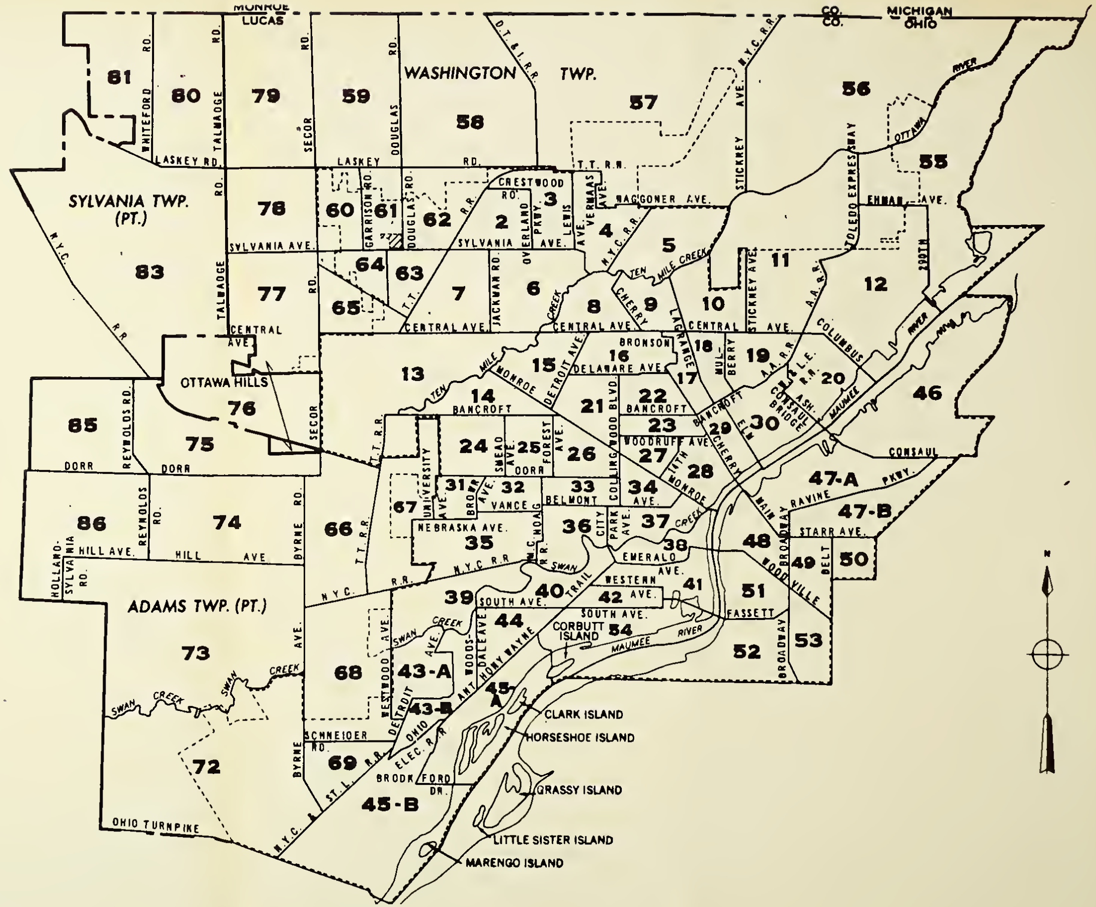
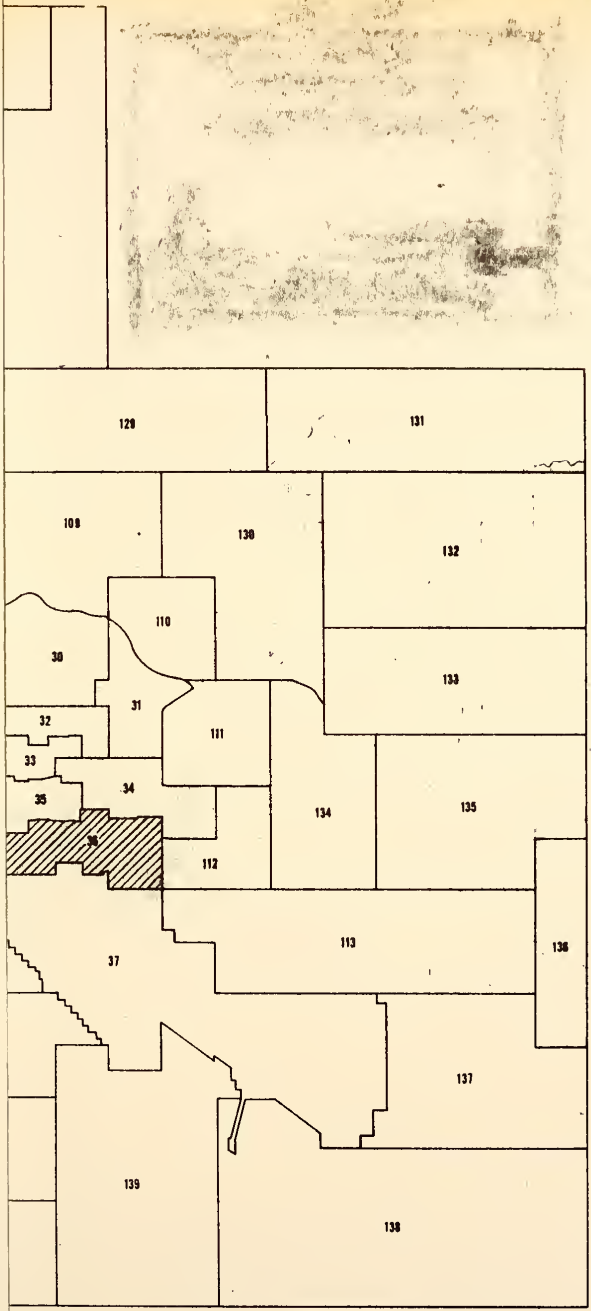


FIG. A-22 TOLEDO, OHIO 1960 CENSUS TRACTS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N STUDY AREA

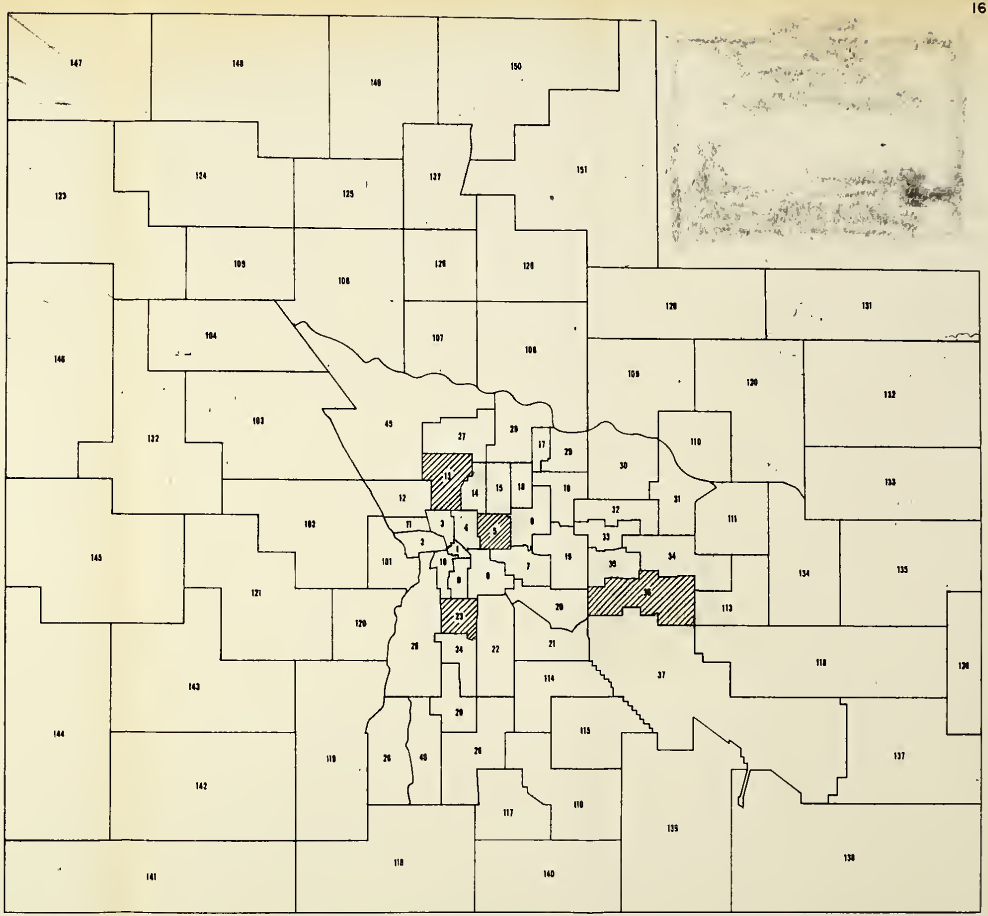


FIG. A-23 TUCSON, ARIZONA TRANSPORTATION STUDY AREA

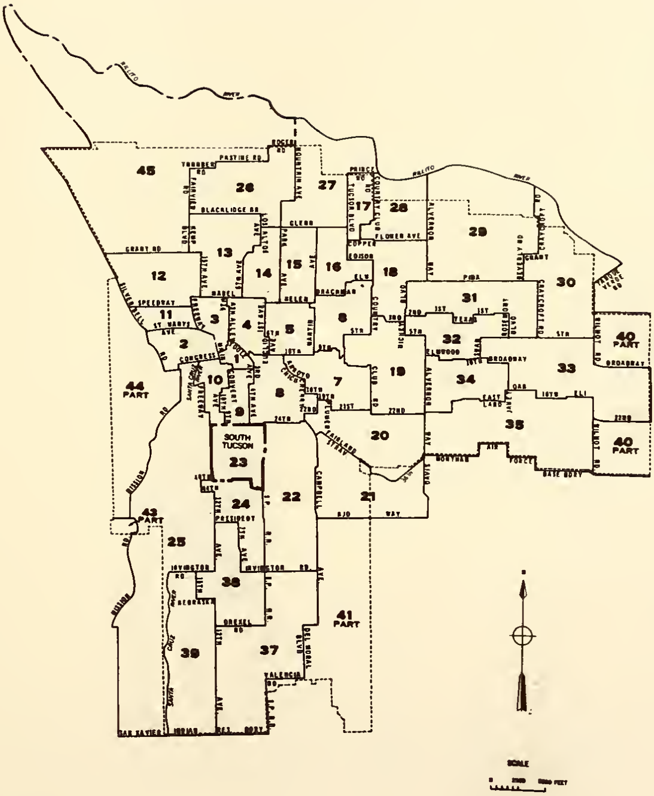
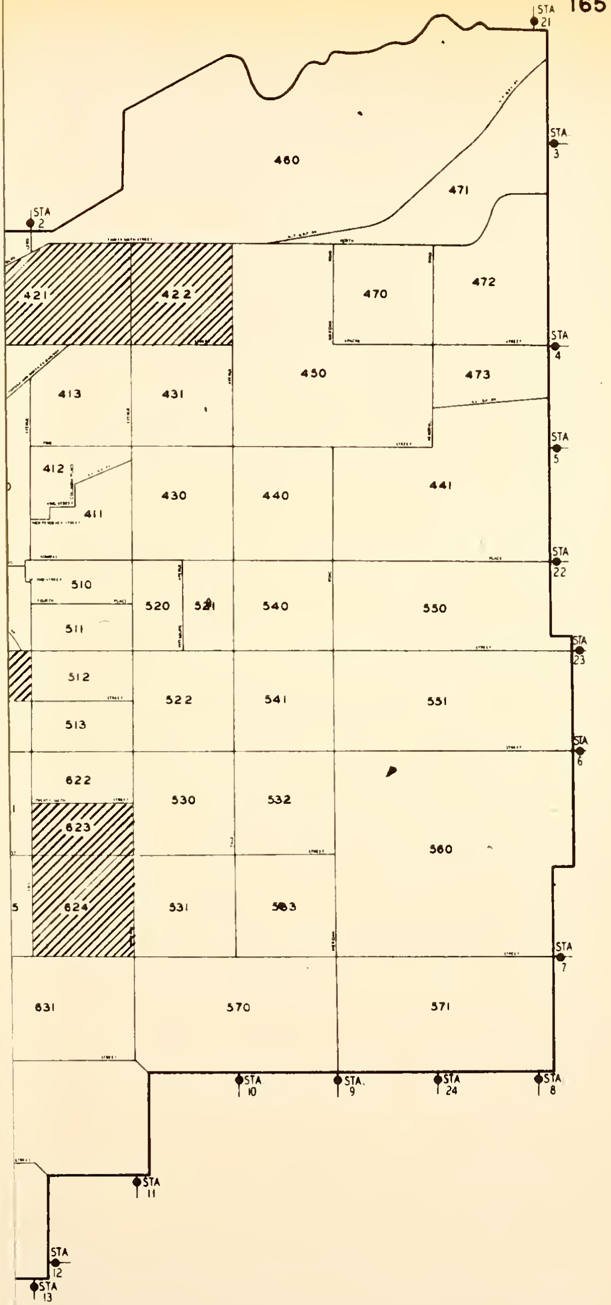


FIG.A-24 TUCSON, ARIZONA 1960 CENSUS TRACTS



TATION STUDY AREA

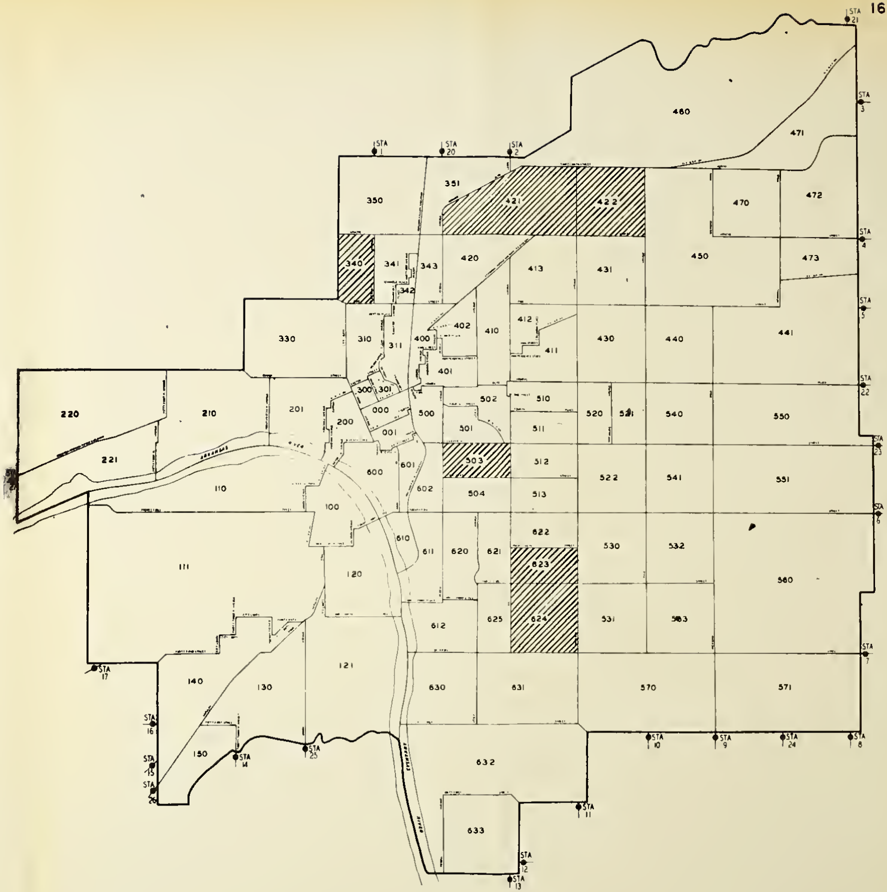
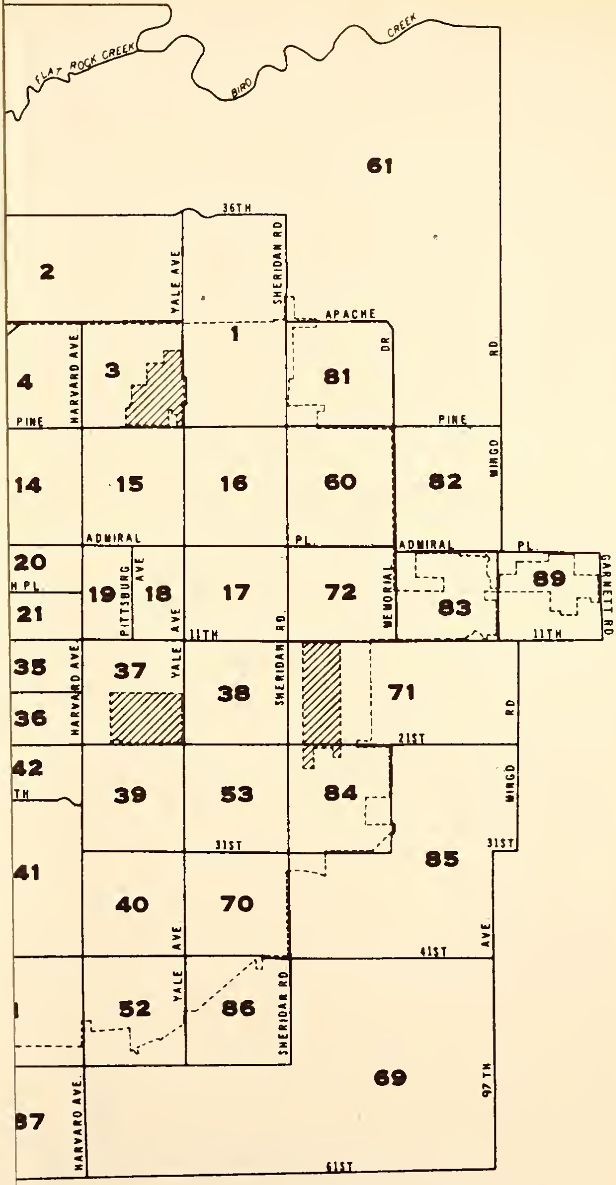


FIG.A-25 TULSA, OKLAHOMA TRANSPORTATION STUDY AREA



1960 CENSUS TRACTS

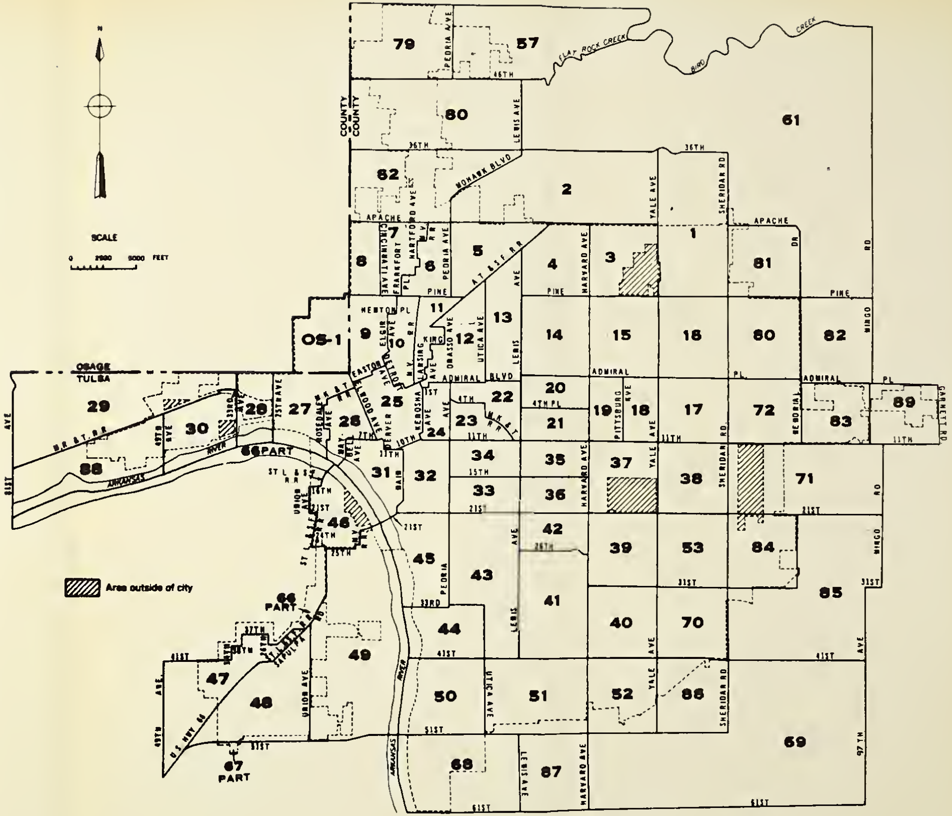


FIG. A-26 TULSA, OKLAHOMA 1960 CENSUS TRACTS

APPENDIX B

DEFINITIONS

1. Hypothesis: A statement about a statistical population and usually is a statement about the values of one or more parameters of the population, with alternatives understood.

2. Null Hypothesis: The notion of formulating the hypothesis for the purpose of rejecting no difference.

3. Type I error: The rejection of a hypothesis which is true. The probability of making a Type I error is sometimes designated as α and when written is commonly referred to as the level of significance.

4. Statistical inference: A conclusion about a population on the basis of what has happened in a sample of observations, the conclusion being drawn with a calculable risk of being in error.

5. Population parameter: Any fixed characteristic of the population.

6. Sample: Any selection of a number of elements from the population.

7. Cordon line: An imaginary line encircling a survey area.

8. Desire line: A theoretical straight line between two zones or two external survey stations, or a zone and an external station, representing one vehicle trip without regards to routes of travel.

9. Destination: The location of the end of a trip.

10. Origin: The location of the beginning of a trip.

11. Trip: The one-way travel between origin and destination.

12. External trip: A trip which crosses the cordon line. It may be either a local trip or a through trip.

13. Local trip: An external trip with either its origin or destination within the survey area.

14. Through trip: An external trip which passes through the survey area without stopping and which crosses the cordon line twice.

15. Internal trip: A trip which has both the origin and destination within a survey area. It may be either an interzonal trip or an intrazonal trip.

16. Interzonal trip: An internal trip with origin in one zone and destination in another zone.

17. Intrazonal trip: An internal trip with both origin and destination in the same zone.

18. Zone: A subdivision of the survey area delimited according to land use.

19. Central business district: The focal point of the entire metropolitan area and often referred to as the CBD.

VITA

VITA

James John Schuster was born December 13, 1935 in Pottsville, Pennsylvania. His primary education was received in that city, and he was graduated from Pottsville Catholic High School in 1953.

He received the Bachelor of Civil Engineering degree in 1957, and the Master of Civil Engineering degree in 1961 from Villanova University.

From 1957 to 1958 he was a Transmission and Distribution Engineer for the Philadelphia Electric Company, Philadelphia, Pennsylvania. From 1958 to 1962 he was an instructor in the Civil Engineering Department at Villanova University. Since 1962, he has been on leave of absence from Villanova University with the rank of Assistant Professor.

He is a registered professional engineer in Pennsylvania, an associate member of the American Society of Civil Engineers, and a member of the American Society for Engineering Education.

ABRIDGMENT

Michael, Harold L. and Schuster, James John, Developement of Travel Patterns in Major Urban Areas, Joint Highway Research Project, Purdue University, Lafayette, Indiana, May 1964.

Descriptors: model evolution; urban vehicular trip prediction; urban traffic characteristics; Michael, Harold L.; Schuster, James John.

This research report is concerned with the development of travel patterns for urban areas by synthesis. To develop the necessary characteristics concerning vehicular trips, data were obtained for fourteen cities from the census and from recent transportation studies of these cities. Each of these cities is a part of a standard metropolitan statistical area with a population less than one million.

Urban vehicular trip prediction models were evolved from the data through the use of multiple regression procedures. The "tear-down" method of model evolution was utilized.

Data, which included populations, areas, population densities, automobile ownership, public transportation usage, income, occupations, distances, school enrollment, workers, automobile usage, locations of employment, value of residences, and many interactions were used as independent variables in the development of the various models. The prediction models evolved were for total vehicle trips in a study area, ratio of external vehicle trips to total trips, ratio of local vehicle trips to internal vehicle trips,

vehicle trips to and from the central business district, intrazonal central business district vehicle trips, vehicle trips generated and attracted by a zone, vehicle trips between a zone and the central business district, and interzonal vehicle trips.

Travel characteristics, including peak-hour travel design hour volume, truck trips, and assignment of traffic to freeways, were also investigated. The latter included an analysis of freeway usage by time ratio, distance ratio, time differential, distance differential, and by a model using all four factors.